AN APPLICATION OF SOCIAL NETWORK ANALYSIS ON MILITARY STRATEGY, SYSTEM NETWORKS AND THE PHASES OF WAR

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Abstract

The research developed in this study will utilize Social Network and Graph Theory terminology and methodology applied to groups of systems, rather than individuals within a given system, in order to shape strategic level goals. With regard to military operations, Social Network Analysis has been used to show that enemy networks and relationships can be accurately represented using weighted layers with weighted relationships in order to identify the key player(s) that must be influenced and/or removed so that a particular effect on the enemy might be realized. Social Network Analysis is therefore a significant tool concerning tactical level of operations that aids in developing a targeting methodology which aids tactical commanders in mission planning, however has never been applied to strategic levels of Command. Like previous key player problems, this research will utilize system attributes and global relational strengths as inputs. The output results will rank order representative systems of interest that satisfy the constraints and desired objectives within a particular Phase of War. This work will apply and extend the tools of Social Network Analysis structure and techniques to a theater level mission.

For my wife for inspiring me by pursuing her degree and raising the twins largely unassisted while I attended this program. Though my boys are not old enough to realize it, I derived much of my strength and perseverance from their smiles, energy, and faith in me.

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Thomas S. Furman

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APPLYING SOCIAL NETWORK ANALYSIS TO MILITARY STRATEGY, SYSTEM NETWORKS AND THE PHASES OF WAR

I. Introduction

"In preparing for battle I have always found that plans are useless, but planning is indispensable."

- Dwight D. Eisenhower

1.1 Background

Social Network Analysis (SNA) in military operations has met with mixed results over the last two American wars: OPERATION IRAQI FREEDOM/NEW DAWN (OIF/OND) and OPERATION ENDURING FREEDOM (OEF). In OIF, SNA was utilized successfully to capture Former Iraqi President Saddam Hussein [1]. The United States Army's initial capture efforts against Saddam Hussein focused on the command-based hierarchical network rather than the familial-based network that eventually led to his capture. The change between network styles was inspired by the US Military's application of hard power and resultant attrition of the hierarchical network. Additionally, the discovery of linkages previously unknown to the analysts indicated the present of a previously unidentified familial and tribal based network. In Afghanistan, SNA was less successful in producing inroads to the capture of Osama Bin Laden [2]. In both the Iraq and Afghanistan campaigns, these individual targets were detected and their locations deduced at the operational and tactical levels. This then offers the question: how would these operations have been defended in the larger strategic context? Or to put it another way, was the hunt for Saddam Hussein justifiable in the strategic perspective of prosecuting OIF? This paper will introduce a generalized methodology for approaching *strategic* level entities that are composed of large numbers of supporting systems. This methodology is scalable, but focused here on desired strategic objectives for various effects.

Militaries, businesses and governments of the future will confront an increasingly complex and multi-dimensional operating environment. From a military point of view, a brief study of modern history and warfare suggests that most major conflicts were either preceded (US Revolution, Algerian revolt (1954), Chinese Civil war (1946)) or followed (Philippine Insurrection (1902), OIF, Vietnam (circa 1972)) by so-called low intensity or insurgent styles of conflict. History also concludes that in low intensity conflicts, large armies and World Powers tend to perform very poorly [3]. Modern examples of this include the French in Indochina and Algeria, Russia's incursions in Afghanistan and Chechnya, and the United States in Somalia and Vietnam. These low intensity conflicts are often characterized by costly and destabilizing operations conducted by a group of people whose numbers are small relative to the population within which they operate. In order to defeat or marginalize these insurgent elements, the support of both the population and the indigenous government is required. This motivates an analysis of how war is fought on the strategic level, addressing if strategic targeting can undercut an existing low intensity conflict or lower the chances of a low intensity conflict occurring following the decisive clash of rival militaries. Unfortunately for the US Department of Defense, most strategic objectives rely on elements of national power outside the purview of the military; this necessitates a so-called Whole of Government (WoG) approach to strategic targeting.

1.2 Motivation

The aim of this research is to provide a robust and agile framework to inform the Whole of Government strategic targeting process by utilizing quantitative social network and operations research techniques. Furthermore, this paper will illustrate the quantitative impact of the DoD's 'Phase of War' concept [4] [5] [6] on the production and valuing of strategic target sets.

In the specific case study of the 2003 Iraq War, post invasion planning was sparse and woefully inadequate [7]. During the build up to the invasion of Iraq, it was common for planners to divide large campaigns into four phases: Deter/Engage, Seize Initiative, Decisive Operations, and Transition. As a military, planning the degradation and destruction of a foreign power, country, or target (in current US doctrine, Phase Three – Decisive Operations) is relatively routine. However, during OIF it did not appear that US targeting accounted for restoring utilities, services, basic functionality, or an operational government. In fact, according to Wright and Reese, "… [planners] allowed Phase Four plans to develop in isolation, thus hindering the establishment of critical linkages and smooth transitions between combat and post combat operations." [7] Though the US OIF strategy was far from a 'total war' concept, the US attacked military systems as well as any military/civilian dual use systems that might have been used by the adversary. In so doing, the US accomplished the capitulation of Baghdad quickly with extremely low casualties; however, US actions also lengthened the time required to restore basic necessities to the population of Iraq. The result was an increase in the strength and intensity of the anti-American sentiment in post-Saddam Iraq, ultimately fomenting the insurgency.

The policy of de-Ba'athification of the Iraqi armed forces and political processes supplied the raw number of trained leaderless personnel and unemployed young men for the nascent insurgency in 2003. Then, the inability to restore basic economic conditions and functioning government prolonged the reintegration process and thus allowed this at-risk portion of Iraqi society to spiral into open rebellion.

An underlying goal of efficient strategic targeting is to minimize the reconstruction phase of a complex societal network in order to shorten the window for a prolonged low intensity conflict. In essence, that means the exercise of all forms of national power including Diplomatic, Informational, Military and Economic (DIME) throughout every Phase of War during an event like the OIF. The only elements of such a campaign that change are the proportions of actions by phase that fall within the various DIME spheres and which agencies generate those actions. This also implies that manipulation or influencing human-based and non-human nodes within a given network is just as important as the efforts of hard power (used here to refer to removing human and non-human nodes within a given network). Therefore, augmenting current targeting practices with network-centric analysis in order to achieve a given effect with fewer rounds, bombs, or ground forces may, in and of itself, greatly improve the current joint targeting process.

Almost all systems contain human elements including governments, militaries, and societies. This implies targeting processes must consider human networks' different properties: they are adaptive, self-repairing at a faster rate than infrastructure, able to grow and cluster when threatened, and will display increasingly binary decision making (for us/against us) when under threat that limits options for influence.

Therefore, we may be able to shape the possible end state density of “against us” networks by seeding human networks with positive influence factors far in advance of applications of hard power. Further, by using means of influence that might be traceable and measureable such as attendance at non-governmental organization (NGO)/healthcare events, opinion polls, or attendance at adversarial indoctrination systems, we can also conduct initial reconnaissance efforts to expose members of so-called Dark Networks. The term ‘Dark Network’ in social network literature refers to “Interdependent entities that use formal and informal ties to conduct licit or illicit activities and employ operational security measures and/or clandestine tradecraft techniques through varying degrees of overt, or more likely covert, activity to achieve their purpose [8].” These human networks would be an aggregation of weighted and layered political, religious, tribal, familial, and other associations that would vary by culture/location/history of the people under consideration.

The construction of these networks, from weighted/layered human based networks to binary/undirected infrastructure/system based networks, would require classified sources and many subject matter experts to synthesize and construct. Furthermore, these networks would be dynamic: computers servers come up and down for repair, businesses grow and change, political movements gain/lose prominence, border crossings and points of entry atrophy, and laws change. Therefore, updating these networks (the human based networks especially) prior to any major engagement is a necessity whether it is trade negotiation, invasion, Information Operations (IO) Campaign (anti/pro), and normalize/sever political relations. Furthermore, these networks should be saved and time stamped into order to gain insight how they change over time and why. By tracking these changes and overlaying them with other intelligence sources, analysts and SMEs may gain insight into how perturbations of the network reverberate throughout said network *as well as* responses of the network to different manners of stimuli (influence/attrition and actions after splintering the network). These are among the reasons why this research avoids the creation of these networks; the process would be a distraction from the utility of the new method of application of SNA. The discussion of follow on actions is contained in Chapter Five.

Insofar the desire to minimize or truncate the time prosecuting low intensity conflicts, a methodology is needed for conducting analysis against targeted institutions, organizations and countries that more efficiently supports a post conflict political environment. In short, this desired tool could be used at the tactical level to collapse and destroy insurgent groups or fielded militaries that can also expand to the address the transnational and strategic level of WoG policies and approaches. Select applications of Social Network Analysis (SNA) provide military planners with a scalable, quantitative tool and an iterative process to address strategic level problems and conduct national level analysis. Social Network Analysis should be used in conjunction with, but not replace, current planning methods to increase operational effectiveness.

1.3 Problem Statement

This research will provide a framework for applying SNA to large strategic level systems of systems by considering descriptive Political, Military, Economic, Social, Infrastructure and Information (PMESII) networks within the DIME spheres of influence and objective-dependant centrality measures in order to create Phase of War dependant target lists. The transition between DIME and PMESII here is significant. Elements of DIME are usually referred to as 'Instruments of National Power' and as such, roughly correlate to foreign operations conducted by the State Department, Intelligence Community, Department of Defense and Department of Treasury (or under the international trade and treaty powers of Congress) respectively. By translating DIME instruments onto PMESII networks, rather than PMESII effects, this traditional paradigm of influence spheres is fundamentally altered. The resulting targeting product can be assigned to a department or agency by capability against a target system as opposed to traditional sphere of influence.

This paper exposes strategic problems to the methods and treatments of SNA to gain insight into more efficient targeting and exploitation of large scale multi-source networks. In so doing, two network types will be proposed: the Dependency Networks and the Will Networks composed of binary relational infrastructure and weighted human structures respectively. Specifically, it will be demonstrated that target sets are dependent upon Decision Maker objectives as described through centrality measures. Further, human based and binary network interplay is used to illustrate Whole of Government utility in war or conflict scenarios. Finally, it is proposed that, when taken together, human influence operations and binary systems interdiction could decrease the effort required to achieve effects and decrease the time required to rebuild networks, thereby limiting the intensity and duration of so-called low intensity conflicts.

1.4 General Assumptions and Limitations

In treating our networks, perfect knowledge is initially assumed for a given network. However, this paper will provide tools and insights to relax this assumption and utilize this methodology on networks with imperfect knowledge. Additionally, the PMESII networks will be independent for illustrative purposes. Independence, however, is not a limitation on this method; when treating multiple networks as layered social networks, methods and tools already exist to deal with these interdependencies. This research is intended for a military audience; nonetheless, the theory and applications are as generalized as possible so as to maintain applicability to any other sufficiently large entity.

SNA is a relatively new field within Operations Research and as such its strategic applications are limited. SNA has been applied to large networks before, but these networks are typically characterized by one element (e.g. the network analysis on Twitter trends in reference to a specific event in the Israeli-Palestinian conflict). There is little in the current literature where SNA has ever been applied to a complex entity like a country or system of systems (with multiple 'styles' of systems represented). This thesis will be limited to static, notional networks to avoid obvious classification issues.

This research addresses strategic level, Whole of Government network analysis problems and exploits the properties of similar layered networks to gain insight into objective oriented targeting. This does not mean the methods or insights gained from this thesis will apply strictly to military personnel or a unique subset of military problems. In fact, with inconsequential changes in labels, this method could easily apply to any complex corporate or inter-organization analysis.

1.5 Scope

This paper discusses strategic level objectives and develops a method for identifying institutions or organizations in order to achieve a strategic effect. Analysis is limited to a sufficiently large or complex entity such as a country or large corporation. This method could be theoretically applied to a regional set of countries or an interrelation of many international corporations who operate across economic sectors; however, under that application, this process would be iterative and presumably multi-echeloned in nature. While the method proposed in this research is therefore scalable, it is also intended for multi-institutional level analysis. Once the subject of interest evolves from key organizations and institutions, then the applicable analytical methods return to the classic interpretations of the Key Player problem [9] [10] [11] [12] [13] within a targeted system or a Value Focused Thinking (VFT) problem concerning which subset of targets is more attractive and why. These discussions will mark the strategic/operational divide for this research, and therefore avoid analysis on networks of individuals in order to maintain the strategic level of aggregation.

1.6 Thesis Overview

Chapter Two (Literature Review) establishes a baseline to explore the expansion of theory and broader applications. Here, the focus is on common terminology, existing methods and current measures of the SNA community upon which this proposed approach rests. Within the same literature review, joint military terminology and doctrine is introduced only to the extent required to illustrate the power of our method under consideration. Chapter Three discusses the methodology of objective based network centrality measures and Phase of War weighting that might yield strategic insight. Chapter Four includes analysis and conclusions from a notional strategic level network as well as robustness discussions related to the relative scales of realistic networks. Lastly, in Chapter Five, will examine the implications of this research and follow on topics for investigation based on the conclusions.

II. Literature Review

"Those who cannot remember the past are condemned to repeat it."

- George Santayana

2.1 Introduction

In this section, the main purpose is to review the underpinnings of strategic targeting and Social Network Analysis as they pertain to this research. This chapter has several objectives. First, an overview of Social Network Analysis (SNA) terminology and associated research is provided. Secondly, graph theory is introduced and current centrality applications are reviewed. Finally, basic military strategy foundations and targeting doctrine are organized and highlighted which this study strives to improve so that associated military decision makers can improve their insight into the strategic decision space.

2.2 Social Network Analysis and Graph Theory

Social Network Analysis (SNA) refers to the art and science of representing a group of individuals or groups in terms of network theory wherein each object (group or individual) is represented as a node and the relationships such as friendship, kinship, and other associations between these objects are represented with a line [14]. These diagrams are often called network diagrams or 'sociograms' [15]. It is important to note that while the network diagram and associated constructs and attributes are important, the manner in which networks are built and understood can often fundamentally change the results of our calculations or alter our insights into the network. This attribute might be viewed as a methodological weakness by some analysts who might prefer an objective, unitless network depiction bereft of bias from the analyst. To the contrary, however, this method allows for the distillation of important groups and individuals and over arching connection traits which allows for the various cultures and groups to be modeled. Indeed, when attempting to calculate methods of influence upon a human based network, there is not a single weighting scheme to describe motivations as these weights are culturally, ethnically and geographically dependant.

2.3.1 Social Networks and Applications

With its roots in sociology and anthropology, SNA has become more mathematically formalized within the last few decades. Originally, SNA studied the interactions between individuals within a group residing in the behavioral sciences disciplines during the 1930's [16]. Three of the arguably most influential figures in the foundation of SNA were Drs. Lewin, Moreno, and Heider [16]. Moreno's seminal 1953 work is most commonly associated with early attempts to quantitatively link SNA with graph theory as it was understood in his time [15]. In fact, many early techniques concerning insights from Sociograms were developed based on Moreno. In recent years, much work has focused on the multi-faceted nature of relationships between individuals within a group. Within each group, members may be linked with relational ties of varying strength including familial, religious, economic, kinship, tribal and other associations [9] [10] [13].

2.3.2 Graph Theory

SNA is mathematically rooted in the discipline of Graph Theory, though there are a few meaningful differences in definitions and assumptions. The theoretical underpinnings of Graph Theory are widely accepted to be Leonhard Euler's solution to the 'Seven Bridges of Konigsberg' problem published in 1736. Euler's work was codified into a mathematically rigid theory of infinite and finite graphs by D. Konig in 1936 [17]; both Euler's and Konig's works provide the mathematical foundation of all graph theory and therefore SNA discussions. Generally, a graph is a depiction of a pair-wise mathematical relationship between two objects. These objects are usually referred to as "vertices" or "nodes" or "actors" and can represent anything from countries to atoms. The lines connecting these objects are called "arcs" or "edges" and represent the strength, characterization or existence of their interaction. Taken together, graphs might depict anything from an individual player within a network and its associated relational ties to atoms in a molecule and their associated bonds that keep the molecule together [18].

Mathematically, a graph, G, is described as $G = (V,E)$ where V is the set containing n nodes, $V = \{p_1,p_2\ldots p_n\}$, and the set E containing m edges between those nodes. In the context of graph theory and current literature, an edge traveling from node a to node b is denoted as (a,b). This indicates a link or relationship between nodes a and b; it is then said that a is adjacent to b. We then let a matrix, $A = (a_{ij})$ be the adjacency matrix of graph G. Here, we must also characterize the type of relationships as found in Figure 1:

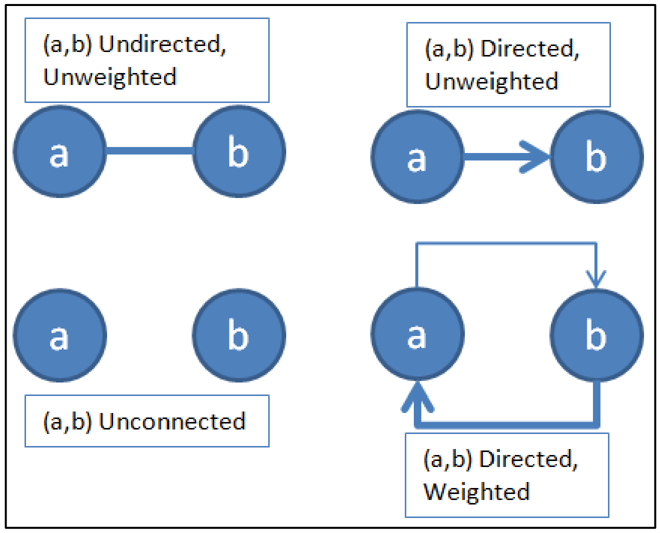

Figure 1: Nodal Relationships

If edge (a,b) does not exist, it is said that nodes a and b are unconnected. (a,b) is "undirected" if the link is equal in both directions, i.e. *a* influences *b* just as much as *b* influences *a*. If the relationship is unbalanced or one-way (e.g. a passive listener to a radio/television station) then we say that the relationship is "directed" and then we represent the link *(a,b)* as an arrow from *a* to *b*. Thus in an undirected network, the values of $a_{ij} = a_{ji}$ and are either 1 or 0, indicating the existence (1) or non-existence (0) of an undirected and reciprocal relationship. Directed networks are ideal for describing asymmetric networks, where $a_{ij} \neq a_{ji}$. This produces an asymmetric adjacency matrix A and therefore, changes the interpretation of certain measures. Also we would say such a relationship is asymmetric if the edge *(a,b)* and the edge *(b,a)* are not reciprocal. This can happen in the case where *a* influences *b*, but *b* influences *a* more. As Brewer and Webster pointed out, directed and asymmetric edges are more appropriate in sociological environments as human interactions are rarely, if ever reciprocal. [19]

2.4 Network Centrality and the Key Player

Solving problems using applications of SNA inevitably involve the use of so called Centrality Measures. Early in the history of SNA centrality was a term used to describe leadership roles [20] [21] [22]. As SNA initially grew from the social and behavioral sciences, this could be expected. The initial goal was, among other things, to identify the individual within a group that maintained the most power within the group [23]. This interpretation of centrality quickly evolved into a multitude of measures to describe various roles and different interpretations of importance [24] [25]. Therefore, Centrality Measures within the context of SNA, are calculations of importance based on the characteristics in which an analyst or DM is interested. As such, SNA practitioners now have plethora of ways to answer the question “who is the most important person in this network?”, or to speak more generally for any given graph G, “Which node is the most important?” Any practitioner of SNA should immediately reply with the question “what is the objective with regard to this network?” or “what is the definition of important here?”

Consider two separate scenarios: Geffre’s analysis concerning the degradation of a dark terrorist network [9] and Bernardoni’s use of Social Network ‘holes’ to inform reconstruction efforts in Afghanistan following the U.S. lead NATO invasion [26]. In both cases, the networks were created in a similar fashion, and yet they used different centrality measures to express different effects. Geffre primarily used Eigenvector Centrality which provided a mathematical preference to a node if that node is connected to other nodes with many other nodes (values nodes’ importance if it is connected to other important nodes). This produced a ranked list of potential targets that might disrupt or degrade the terrorist network's actions or capabilities. Bernardoni's used the occupation of structural holes [27] to suggest the creation of reconciliation ties between disparate ethnicities and focus resources to thereby create a more inclusive society and more stable state. Central to the idea of structural holes is Betweenness Centrality, wherein a node's rank is determined by the number of geodesic paths on which said node exists between all pairs of nodes within the network [28]. These two examples illustrate that, not only does the manner in which networks are built matter, but similarly, our choice of centrality measure grants us different insight based on our final objective.

In fact, while the field of SNA has witnessed an explosion of specialized centrality measures within the last twenty years, many of these measures are highly correlated [29] and therefore provide little new information for a given network. However, there are four measures which have withstood academic scrutiny so as to be considered foundational to the field of SNA: Degree, Eigenvector, Betweenness and Closeness Centrality [30]. From this list of four, there are two that have not been previously discussed here: degree and closeness centrality.

Degree centrality is simply a measure of the number of nodes to which a particular node is attached. Great care must be taken when concluding any insight based solely on degree centrality as special attention must be afforded to the type of relational ties the edges represent. An example of an individual with high degree centrality might be a food delivery person or a manger in a highly micro-managed work environment. Firing the food delivery person (removing that node from the network) may not have the same impact or degradation on the network as removing the micro-managing boss. The last measure is closeness, which refers to the mean distance from a node of interest to all other nodes in the network [31]. Here the higher the rank of the metric, the lower the node's average distance is from every other node in the network.

2.4.1 Calculating Centrality

Direct calculations for these four primary Centrality Measures can be performed by hand for small networks in a relatively straight forward fashion, however, most naturally occurring networks are quite large. Therefore, practitioners must use algorithms to efficiently calculate these and other measures. Consider the following simple undirected unweighted network:

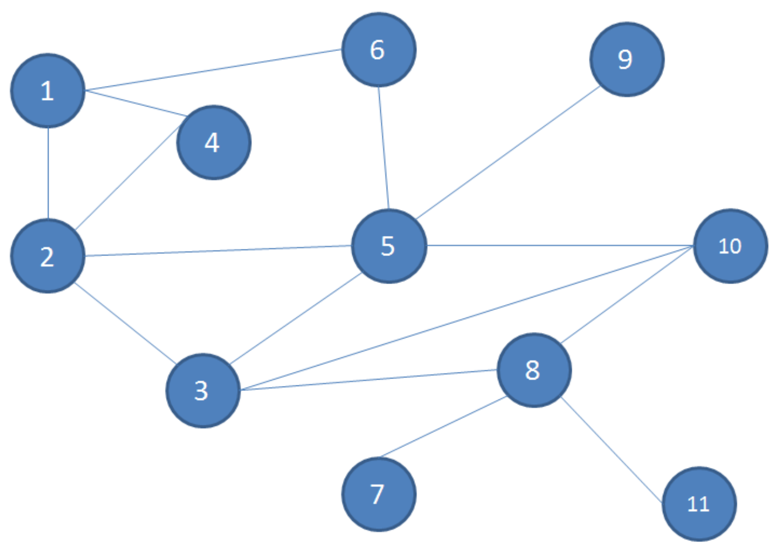

Figure 2: Sample Network

With its associated Adjacency Matrix, A:

Table 1: Sample Network Adjacency Matrix

Adjacency Matrix

Node	1	2	3	4	5	6	7	8	9	10	11
1	0	1	0	1	0	0	0	0	0	0	0
2	1	0	1	1	1	0	0	0	0	0	0
3	0	1	0	0	1	0	0	0	0	1	0
4	1	1	0	0	0	0	0	0	0	0	0
5	0	1	1	0	0	1	0	0	1	1	0
6	0	0	0	0	1	0	0	0	0	0	0
7	0	0	0	0	0	0	0	1	0	0	0
8	0	0	1	0	0	0	1	0	0	1	1
9	0	0	0	0	1	0	0	0	0	0	0
10	0	0	1	0	1	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0

Degree Centrality, C_D, is simply the number of adjacent (connected) nodes to a source node and can be calculated via a summation [25]:

$$C_D = \sum_{j=1}^{n} A_{ij} \qquad (1)$$

Closeness Centrality C_C, for any node, n_i, is a measure derived from the inverse sum of the distance from that node to all other nodes in the network. 'Closeness' centrality aims to determine how 'geographically central' a node is relative to the rest of the network. In Equation 2, the term $d(n_i,n_j)$ is the distance between node i to node j [25]:

$$C_c(n_i) = \left[\sum_{j=1}^{g} d(n_i, n_j)\right]^{-1}, \text{ where } g \in \{1 \ldots n\} \qquad (2)$$

Betweenness Centrality, C_B, is related to Closeness Centrality in that paths are considered, however, Betweenness Centrality measures the number of times a node of interest, n_i, lies on the a shortest path, g_{jk}, between any two members of the network. The betweenness can be thought of as a 'go-between' measure that depicts the extent to which members of the network are dependent upon the target node to keep the network connected. Betweenness Centrality can be calculated directly [25]:

$$C_B(n_i) = \sum_{j<k} \frac{g_{jk}(n_i)}{g_{jk}} \tag{3}$$

Finally, Eigenvector Centrality [25], related to Gould Index [32] values, is a representation of importance based on the relative importance of a node's connections. In other words, Eigenvector Centrality prefers nodes that are adjacent to other highly connected nodes. From linear algebra, we can calculate an eigenvector, λ, of a matrix by recalling:

$$(A - \lambda I)C = 0 \tag{4}$$

λ is an eigenvector of matrix A if and only if there exists a non-zero vector C such that Equation 4 is true. Matrix I is the identity matrix. If A is an n x n square adjacency matrix, then solving for λ in Equation 5 below will yield a set of eigenvectors (solving eq. 1.5 below) and an n x 1 matrix associated with each eigenvector λ.

$$\det(A - \lambda I) = 0 \tag{5}$$

Defining the principal eigenvector as $\lambda_o = max\ |\lambda|$, our eigenvector associated with λ_o is the result of substituting $\lambda_o = \lambda$ and solving Equation 4 for C. This will produce an n x 1 matrix, C_o, where the value of C_i is the associated eigenvector centrality for node n_i.

Table 2: Sample Network Measures

	Centrality Measures			
Node	Degree	Close	Between	Eigen
1	2	0.038462	0	0.1739
2	4	0.055556	0.355556	0.3976
3	4	0.0625	0.333333	0.484
4	2	0.038462	0	0.1739
5	5	0.058824	0.411111	0.4752
6	1	0.038462	0	0.1446
7	1	0.034483	0	0.0994
8	4	0.05	0.377778	0.3268
9	1	0.038462	0	0.1446
10	3	0.052632	0.1	0.3912
11	1	0.034483	0	0.0994

Table 2 shows the calculations for all above described Centrality Measures for the sample network found in Figure 2. Even in this extremely small network, it can be seen that each centrality measure produces a uniquely valued list from one to *n*. Notice node 5, in this example has the highest degree centrality, but not the highest closeness or eigenvector centrality. Therefore, determining which nodes are 'central' or 'most important' to any network given a network is unanswerable unless we discuss which properties make a node important within the current decision space.

2.5 Dark Networks and Centrality Robustness

Much of the discussion of networks and the ensuing traditional analysis rests on the assumption that near perfect knowledge is known concerning the true structure of the network, these are co-called 'bright networks.' However, as is more often the case, an analyst may not have perfect information or the network under analysis purposefully behaves in a way that eludes detection. Networks known as Dark or Clandestine Networks are ingrained with “secrecy as a part of its existence” [33] and must limit recruitment within pre-existing networks of relationships [34]. According to McCormick and Owen, a clandestine network is characterized by three factors: size, location, and structure [35]. For these networks to maintain freedom to operate, they must evade detection or significant attrition. Therefore they must balance the size of the organization and its capacity to operate; the greater the group’s size, the easier said group would be detected. Also, in order to maximize operational impact, small cells would have to be located close to an adversary’s interests. Likewise, such a group’s structure must be necessarily compartmentalized due to operational security concerns. Very few (if any) highly protected individuals would have complete knowledge of the network and its various efforts and operations; furthermore, communication between these individuals and the organization would be highly covert and extremely difficult to penetrate [35].

2.5.1 Centrality Robustness

The most often cited weakness of SNA is most often the assumption of perfect information. Whether a network is inherently dark as in the case of terror organizations, organized crime, or coincidentally dark as in the case of missing information about an accessible network, the problem from the practitioner’s point of view is the same: inaccurate knowledge of the network. Fortunately, Borgatti, Carly and Krackhardt looked at this very question. Their study reviewed the sensitivity of four measures (degree, eigenvector, closeness and between) against four types of data error: Node addition, node subtraction, edge addition and edge subtraction. They concluded three very important points concerning the four fundamental Centrality Measures that will support the viability of this research [30]. First, in terms of robustness, all four measures are comparably robust with betweenness centrality being slightly less sensitive to errors in the data. Secondly, all types of errors had similar effect on accuracy. Generally speaking, all four centrality measures are still robust enough to be useful with an error rate under approx 10%. The study does caveat this last conclusion by pointing out that misidentifying a key node in an infectious disease scenario could be disastrous [30]. However, by remaining at the strategic level and creating phase dependent methods, this study hopes to minimize the impact of imperfect information. By remaining at the strategic level, the structure and composition of individual systems is largely aggregated into a single node. Then too, the connections between two strategic systems also represent an aggregated connection. This is much like detecting a celestial object in deep space by way of gravitational effects; the physicist need not know the topography or composition of a planetary body to know that such an object exists. Therefore, even intergovernmental clandestine impacts or effects can be estimated so long as the overall relationship is correct and the target system can be ascertained. The detection of the specific clandestine sub-network, office or group lies in the operational domain of system specific exploitation. Thus, it is highly unlikely and therefore assumed that strategic nodes and relational edges between those nodes would be undetectable at a greater rate than the 10% found to be significant by Borgatti, Carly and Krackhardt.

2.5.2 Treatment of Dark Networks

In the context of this discussion, imperfect or dark networks will be aggregated to the institutional level as discretely as possible. For example, in the case of one business trying to compete favorably against another business, perhaps the adversary business has only a handful of distribution points in a given region. Rather than describe this adversary's distribution operation to a high resolution network at an individual level, we could describe the system in terms of sub-contractor companies or support systems present. This approach would initially allow us to determine importance through an applicable centrality measure based on our objective (distribution centers implies a flow of goods, perhaps betweenness and closeness would be appropriate) and conserve intelligence gathering resources until a subset of organizations is identified and greater knowledge is required before influence or action can be applied. This approach will minimize the impact of misidentifying a key individual at the onset as a result of imperfect information while simultaneously conserving finite intelligence gathering resources.

2.6 Weighting Techniques

The elicitation of weights from a decision maker is one of the most important tasks an analyst can perform with regard to most decision analysis methods. Because these weights mathematically represent the DM's interest, focus, and establish his or her priorities, correctly eliciting values and weights from a DM is essential. There are several methods by which an analyst might capture these values. Most methods for eliciting values for weighting purposes were established by Multiattribute Utility Theory, where the utility of an alternate exists within [0, 1]. As such, these methods must adhere to decision theory axioms and are predicated on the belief that there exists a worse case alternative that achieves zero utility and a theoretical best case alternative that scores a perfect one [36].

By way of example, this research considers two types of elicitation methods. The first is direct elicitation and the second is swing weight elicitation. Direct elicitation is simply an ordinal rank based method but perhaps the most damaging if performed incorrectly. In direct elicitation, one simply asks the decision maker how he/she ranks each element relative to the others. In large models, this is prohibitively taxing and unfeasibly complex to accomplish in a realistic amount of time. This approach also carries with it a multitude of inherent biases that an unprepared DM might introduce into the model [36]. As an example, two methods of direct elicitation weighting are Rank Sum and Rank Reciprocal. In both Equations 6 and 7, r_i is the ordinal rank associated with the i^{th} element. In the Rank Sum method, the weight of the i^{th} element, wt_i, in a set of K elements is calculated according to Equation 6. Furthermore, the Rank Sum method will produce a set of weights with a linear relative relationship between every element; this is both easily calculable but may result in an over simplification of a particular DM's beliefs.

$$wt_i = \frac{K - r_i + 1}{\sum_{j=1}^{K}[K - r_i + 1]} \tag{6}$$

Another method for inferring weights from a DM's ordinal ranks is to use the Rank Reciprocal method. Calculating weights using this method is also straight forward as seen in Equation 7 below.

$$wt_i = \frac{1/r_i}{\sum_{j=1}^{K}(1/r_i)} \qquad (7)$$

The Rank Reciprocal method produces a set of weights that will heavily favor the first and second-ranked elements like those of a negative exponential curve. This method will break ties achieved through otherwise equal tradeoffs that would result from the use of the linear Rank Sum methodology.

In swing weighting, an analyst can infer weights based on the DM's comparative descriptions of attribute level combinations. A simple approach is asking a DM to allocate 100 points representing their belief of importance among various attributes. A potentially less biased approach to swing weighting is an extensive pair wise comparison matrix between all attributes under consideration [36]. The choice of weight elicitation method will vary according to the DM for which the study is conducted. The weights shown in Table 3 are provided as an example of a final product resulting from such an elicitation.

2.7 The Foundation of Modern Military Joint Operations

Military communities have their own terminology and lexicon, as well as methods for discussing campaign planning and methods of warfare. The nature of warfare has evolved dramatically since the early 1990's [6], marked mainly by the development of precision technologies including unmanned vehicles, the speed of communications and the interdependencies between the service branches under the tenants of joint [5] and combined war [4]. The Department of Defense (DoD) has attempted a unification process over the previous decades to create a standard joint language and the processes by which the department's personnel create plans. These are codified in Joint Publications (JPs) and form the common operating starting point at which all joint planning begins.

Since passage of the Goldwaters-Nichols Department of Defense Reorganization Act of 1986 and following the First Gulf War (1990-1991), military strategists grappled with the idea of both US Army-centric targeting as well as the formal concept of 'Joint Targeting.' As Bartell illustrates, "In the joint environment, the problem [of targeting] is more profound; there is insufficient doctrine to assist the…Commander in synchronizing the fight and maximizing combat power." [37] In the time since Bartell wrote his criticism of the state of US joint doctrine in 1997, the DoD has attempted significant progress in terms of Joint High Intensity Warfare; however synchronization of targeting inside the DoD and across US DIME capabilities remains problematic.

The invasion of Panama, OPERATION JUST CAUSE, in 1989 represented a substantial step toward true unified joint command as well as provided a proof of concept of the new Goldwater-Nichols Act organization. The two operations that succeeded it built upon early joint success and became the model of joint lethality: OPERATION DESERT SHIELD and OPERATION DESERT STORM in 1990 and 1991 respectively. These three operations serve as the bedrock upon which our current joint doctrine stands. As a result of this doctrinal shift, the US-led coalition invasion of Iraq toppled the Saddam Hussein Ba'ath Government in less than three months (20 March to 1 May 2003) while incurring less than 200 US combat deaths [38]. Much of this improvement came about through early applications of so-called 'effects-based' planning [39] which focused joint commanders on conditions and points of influence on the ground, rather than individual service component missions. These joint effects can be realized through any conceivable application of military power; they can be destructive or constructive, offensive or defensive, lethal or non-lethal in nature.

2.8 Military Targeting and Strategy

Military targeting and strategy differs from civilian organizational or corporation strategy, however the process of strategy creation is the same for any business as it is for the military: establish a vision for the future, gather information on a rival, set leadership-driven objectives, perform analysis against adversary weaknesses while mitigating your own, create a plan to exploit the rival's perceived weakness using your perceived strength, execute the plan, assess and revise the plan as required. In this section, military targeting and strategy formulation is discussed as a proxy for general targeting and strategy development. Although the following section is written to appeal to members of the profession of arms, it holds general applicability to anyone in executive level leadership or analysis roles.

2.8.1 Targeting

JP 3-60 defines targeting as, "…the process of selecting and prioritizing targets and matching the appropriate response to them, considering operational requirements and capabilities." In true military fashion, this is written succinctly while remaining unconstrained in order to allow for an individual commander's interpretation. The targeting process that is enshrined within JP 3-60 requires the commander's input for preference of the appropriate response (engagement method) and operational requirements. In practice, the majority of target planning in the US Army is executed by military intelligence and certain combat trained Officers and non-commissioned Officers. An operational planner or strategist may join the group at a strategic level or if a given operation is to take place in the far future. The reasoning behind this practice is traditional and pragmatic; combat specialized personnel are trained to look at physical targets across a battle space and intelligence personnel are present to provide possible enemy reactions or impacts. This arrangement of expertise is acceptable so long as the organization's mission is related to offensive operations and its associated degradation and destruction of enemy militaries.

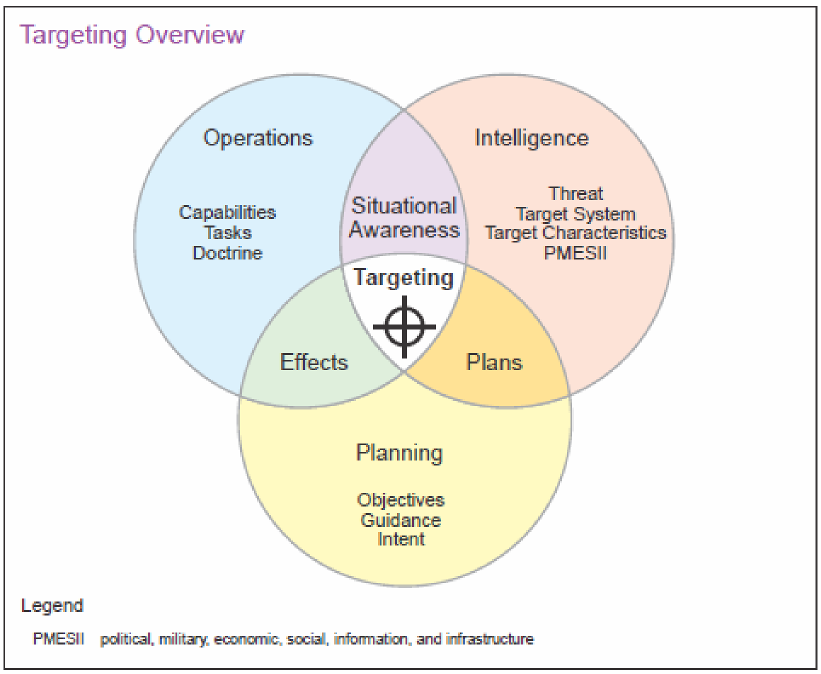

Figure 3: PMESII - Targeting Overview [5]

Figure 3 represents this trinity of staff capabilities and their relative contributions to the joint targeting process. Here, the operations capabilities are provided by the aforementioned combat trained personnel. As a process, formal military targeting follows Figure 4, and both begins and ends with the Commander's objectives and end state. We will use this generalized targeting template in Chapter Three to overlay how the methods of this thesis would apply within the existing construct of the military decision making process.

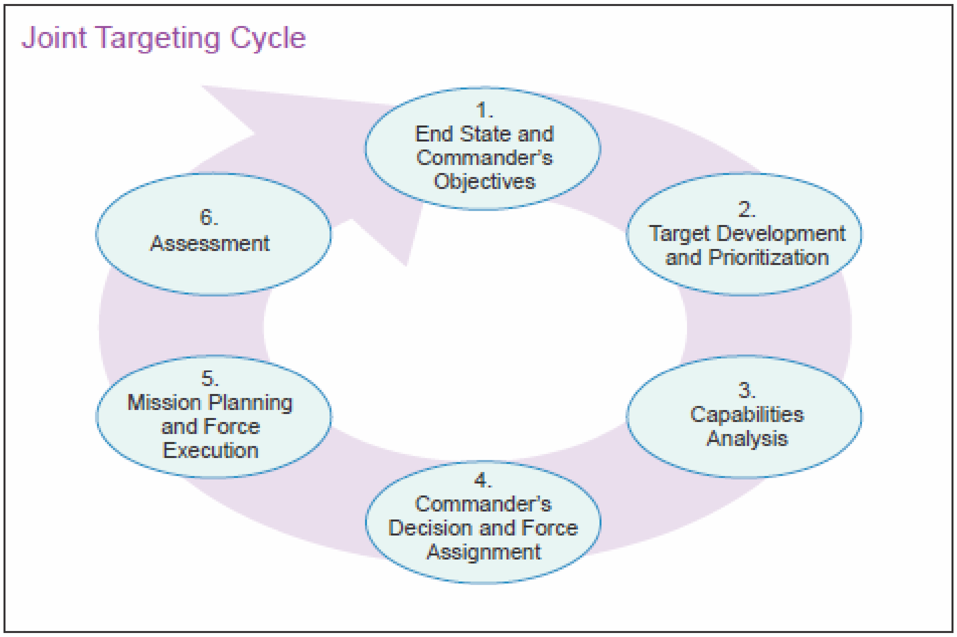

Figure 4: Joint Targeting Cycle [5]

2.8.2 Strategy and Clausewitz

The intent for this section is not to provide an expansive or historical view of military strategies, but to provide a link between strategy and targeting in the form an introduction to Clausewitzian Centers of Gravity (CoG). The Joint DoD definition of strategy is, "The art and science of developing and employing instruments of national power in a synchronized and integrated fashion to achieve theater, national, and/or multinational objectives [40]." Here, the instruments of national power refer to the so-called Diplomatic, Information, Military, and Economic (DIME) powers. Under the military form of national power, military strategists look at degrading or influencing the entire spectrum of an enemy's instruments of national power. While multiple military philosophers' opinions on national strategy provide an excellent backdrop against which we may couch current strategic thinking, only one adds clarity to our problem of mathematically describing the frequency and strength of inter-system relations and their subsequent targeting for a specified effect. The DoD draws substantially on one particular strategic term that any analyst must be prepared to address: the 'Center of Gravity.'

Carl von Clausewitz's (1780-1831) concept of the enemy's CoG was most likely a metaphor borrowed from the mechanical sciences, an older term for physics, of his time. To Clausewitz, the CoG was, "…always found where the mass is most concentrated, and just as every blow directed against the body's center of gravity yields the greatest effect, and—moreover—the strongest blow is the one achieved by the center of gravity, the same is true in war [41]." Some in the operational and tactical sphere of operations have taken this concept very literally and determined enemy CoGs based on their highest concentration of forces or upon the highest density of capability. This interpretation follows localized intuition in that this method produces highly effective ways to destroy an enemy's ability to fight, but in the strategic frame, may not produce the desired effect or address the larger issue of adversary will. Indeed, even Clausewitz recognized that an enemy's CoG may be external to the armed forces or may even lie with an ally to that force if that ally is the dominate entity in an enemy coalition [41].

Here, contextual caution must be exercised. Clausewitz was a veteran of the Napoleonic Wars in the early 18th century. Wars and battles during this period were fought using linearly arrayed men marching mass formations in open field; concentrations of artillery, volley fire, and organizational courage were the usual determining factors in the outcome of a discrete battle. In his critique of current use of CoGs in military doctrine, Echevarria argues strategists, military or otherwise, should think of a CoG as a focal point that serves as a unifying force that sustains enemy action or forces [42]. This last interpretation of focal points is supported by our later calculations and resembles Figure 5 below. In military terms, there can be multiple operational CoGs; however, they must all be 'nested' or supporting the strategic objectives and with them, affect the strategic CoG.

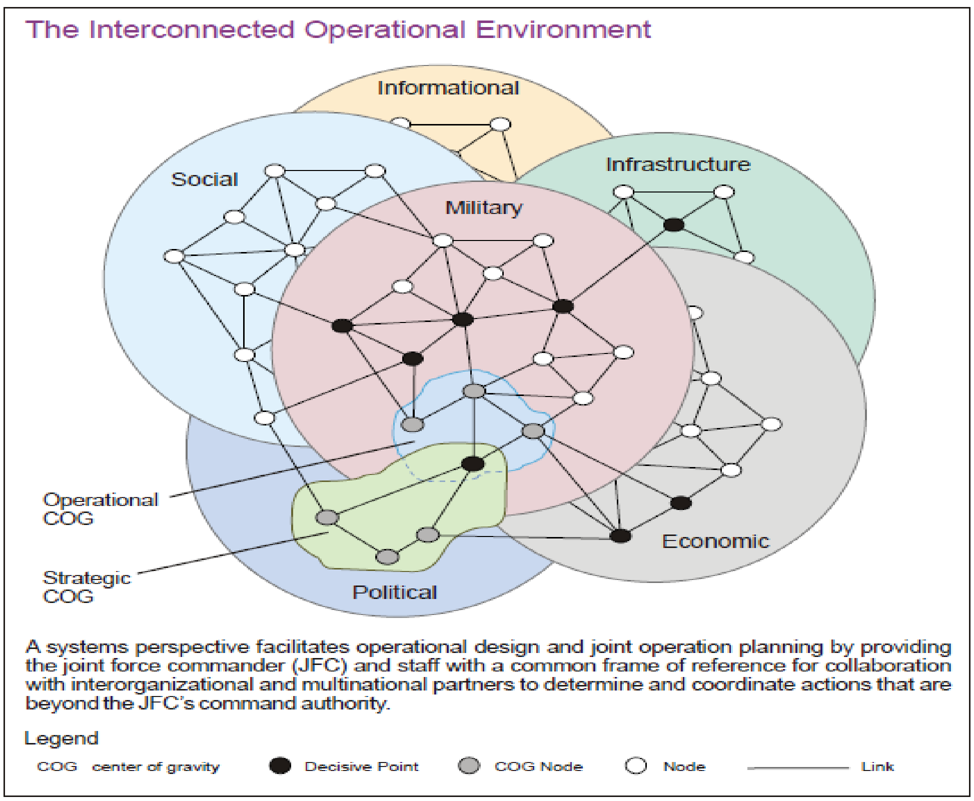

Figure 5: Operational Environment [43]

2.8.3 Military Metrics

Operational requirements are functions of the PMESII concept; PMESII stands for political, military, economic, social, information, and infrastructure. In simulation and military doctrinal terms, PMESII are treated as state variables that represent the 'current state of the system' for which entity is under analysis. Consequently, this is why PMESII is located under the intelligence prevue in Figure 3; the military intelligence community is currently charged with measuring PMESII effects. Furthermore, the DIME concept revolves around actions that could be introduced to the system to inspire changes in the PMESII state variables. These are measures used to establish measures of merit against which missions and targets are ranked. In Chapter Three, this research will build on the centrality foundations as well as weighting methods of Chapter Two and apply them to a phase strategic targeting methodology which is both dependent on objectives and the Phase of War.

III. Methodology

"A problem well stated is a problem half solved"

- Charles Kettering

3.1 Introduction

This chapter focuses on theoretical and applied methods for describing a strategic level complex system. It will be demonstrated that a large system, say a country, can be adequately described by structuring its institutions into two separate networks: the dependency and will networks. The undirected dependency networks are composed of vital civilian infrastructure, food and water systems, and system wide communications. Arrays of infrastructure and existence of military bases and units are relatively stable; information systems might be constantly fluctuating with regard to capacity and content but existence and persistence of information systems as well as their underpinning infrastructure are adequately stable to be described with dependency networks. The directed 'will networks' are composed of mostly human driven systems such as political institutions, social sectors, and commercial centers; these networks capture unbalanced relationships and might be characterized as influence networks. Subsequently, multiple treatments of our dependency and will networks will be explored and analyzed. The goal of this research is to mathematically determine infrastructure 'Centers of Dependency' from our dependency networks and analogous 'Centers of Will' from our will networks.

3.2 Proposal and PMESII Deconstruction

This first step in this method begins with a suitably large example and construction of a notional set of networks upon which we can act. As previously stated in Section 1.2, constructing these networks is sensitive in nature and requires access to means and methods not within the scope of this research. For this method to apply, the entity under analysis must be sufficiently complex so as to allow for the construction of supportive networks. Because this research is designed to identify key systems or institutions for further influence or action, calculations must be performed against sets of targets to array them against the accomplishment of some effect. As Allen states, "…effects-based operation is the employment of all instruments of national power [DIME] against opposing [PMESII] capabilities to create a desired effect or end state." [44]

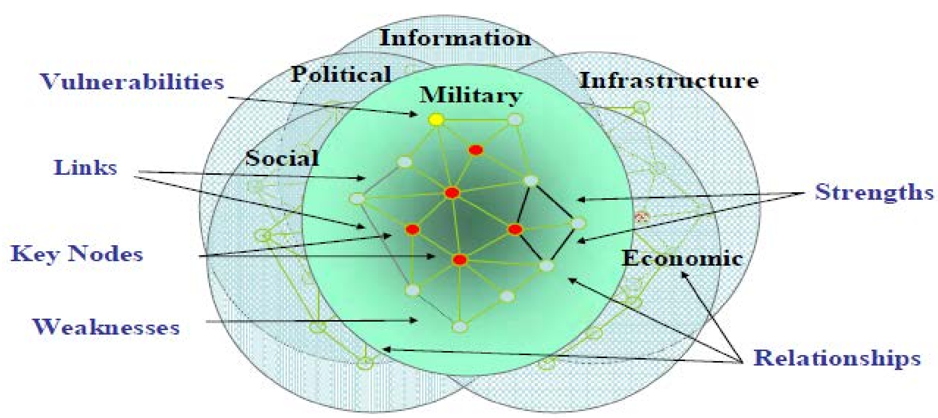

Figure 6: PMESII - A System of Systems Understanding [45]

Therefore, the goal for this method is to inform a Whole of Government approach to strategic targeting. In order to accomplish this, separate PMESII attributes of an adversary entity into separate networks representing each PMESII attribute. The first subset of networks will include so-called “hard” networks of physical structures that can be represented as undirected, with binary valued edges that indicate either the existence or non-existence of relationship. These networks are the ‘Dependency Networks’ as they represent physical infrastructure such as telecommunications nodes, electrical power grids, water, food, and emergency services systems. Considering military specific targets and informational systems, the Dependency Networks contain the Military, Infrastructure and Information attributes from an adversary’s PMESII capabilities. Another discriminator for dependency networks, other than characterizing the relationships between the nodes, is the fact that systems within these networks do not change quickly over time.

The remaining PMESII attributes, political, economy, and social will rely more on time dependent trends and localized effects and as such, will require Subject Matter Expert (SME) elicited influence-based networks classified as ‘Will Networks.’ The will networks describing the P, S, and E attributes will therefore resemble the dependency networks except that, in place of binary linkages, we will have continuous directed influence probabilities between 0 and 1 within systems. For example, to construct the P (political) matrix, Subject Matter Experts (SMEs) would provide input to capture the influences between political entities or offices and other members of the political arena. Figure 7 below shows an overview of how these networks feed the larger decision context of this research:

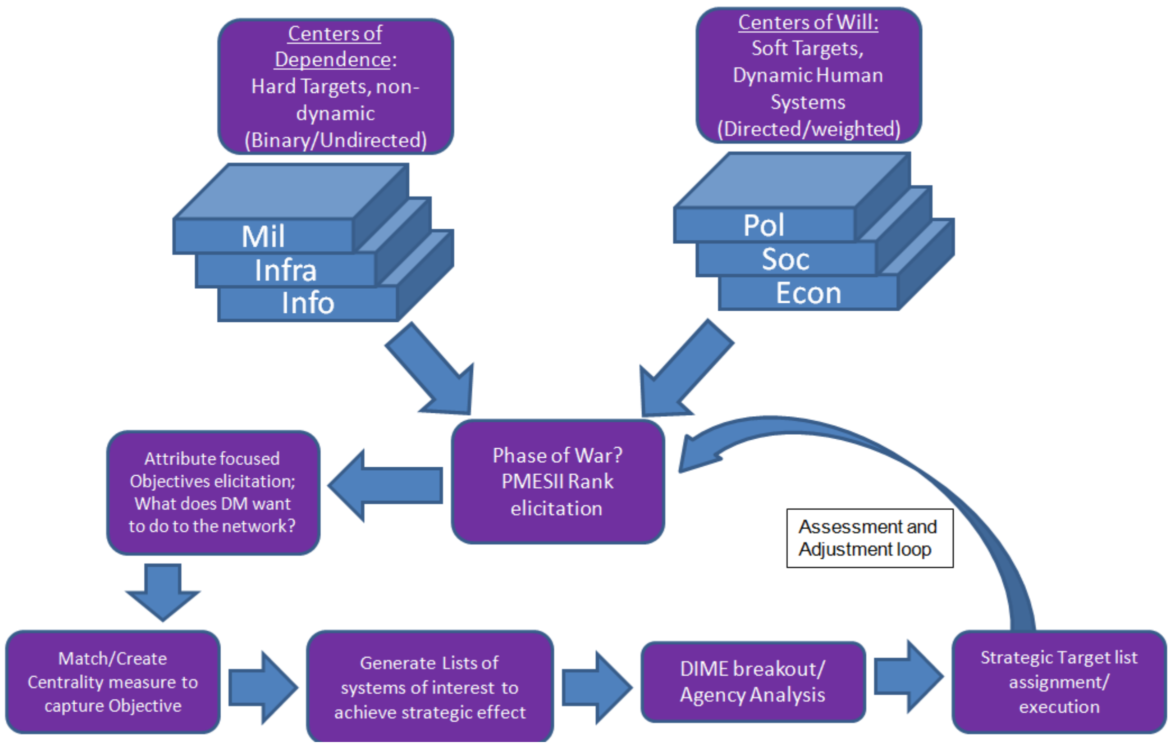

Figure 7: Strategic Targeting Process Overview

Once these networks are constructed, an attribute weighting by Phase of War, W_i, where i = {0, 1, 2, 3, 4, or 5} representing our six doctrinal Phases of War is elicited. These weights should adhere to Equation 9 below and sum to one during each Phase of War. The Phase of War determination and the ancillary weighting of each of PMESII layered will produce the first weighting matrix in this process. This will be a matrix that describes how important each attribute within the PMESII model is most important to a decision maker within each Phase of War. Then we will perform centrality measures on each attribute network, C_j, individually based on the objective set against that network. Here, j contains the set of our PMESII layers, or $j = \{P, M, E, S, Infra, Info\}$. This will produce six weighted lists, $\{S_j\}$ for each attribute layer, each of which will be normalized and multiplied by its respective

Phase of War weight as appropriate to the Phase of War of interest. The normalization method utilized with respect to each centrality measure will be the '2-norm' formulated generally by equation 8:

$$\left\| C(x_i) \right\|_2 = C(x_i) / \sum_i (C^2(x_i)^{1/2}) \tag{8}$$

Equation 8 produces the set of normalized centrality measures for a particular attribute regardless of which measure is used. This normalization method is used in order to prevent centrality measures which might score in whole numbers (e.g. Degree Centrality) from overwhelming the value model while still maintaining internal ordinal ranking and relative scale between scores. These weighted and scored systems will then be combined in one list, $\{S_{i,\, Total}\}$, which will produce a weighted, scored and combined master list of systems ordered by importance which could then be used to assign limited resources in the most beneficial way possible. Of note, the set $\{S_{i,\, Total}\}$ is indexed by Phase of War. Therefore, each Phase of War will have its own unique master list of systems due to the weights within the i^{th} phase as well as the set of objectives described by our attribute C_j*'s*. Equation 11 shows how this method constructs a weighted list from our attribute networks, $G_j(V,E)$.

$$\sum_i^n W_{ij} = 1 \tag{9}$$

$$\{S_{i,\, j}\} = W_{ij} C_j \{G_j(V, E)\} \tag{10}$$

$$\{S_{i,\, Total}\} = \{S_{i,\, P}\} \cup \{S_{i,\, E}\} \cup \{S_{i,\, M}\} \cup \{S_{i,\, S}\} \cup \{S_{i,\, Infr}\} \cup \{S_{i,\, Info}\} \tag{11}$$

3.3 Constructing the Network

As previously stated, the scope of this thesis does not detail trade secrets or classified methods by which a business or government would create these networks. However, this section will discuss the general scale of the problem. Building the military network for inclusion as a Dependency Network would require a deeper analysis than simply locations of military bases. Not only would such a network need to represent concentration of weapons and personnel, but it would also account for systems such as Petroleum, Oil, and Lubrication (POL) concentrations, transportation nodes, command and control nodes, railway systems (for the transportation of heavy ground based weaponry), and depot level maintenance facilities. The inclusion of these various supporting networks might also be a function of the current Phase of War. For example, if Iraq was using this method to analyze weaknesses within the American Military during the 2003 Invasion, considering strategic infrastructure within the continental United States would not have had an effect on tactical American Armor incursions into Baghdad. The timeline for OIF Phase Three (Dominate) limited Iraq's options from the strategic to the operational/tactical timeline; and thus it decreased the set of viable targets for inclusion in the analysis.

With this example in mind, we must introduce the concept of effects-based operations over time. This effect over time is used to distinguish a "strategic effect" from an "operational effect." Furthermore, the strategic effects of interest are also a function of the Phase of War that currently characterizes relations with an adversary. Changing Iraq's point of view to a Phase Two (Seize Initiative) against the United

States, their strategic options would be legion and include both Center of Will targets (Congressional lobbying, appealing to the UN, and direct engagement with the American people, etc) and Center of Dependency targets (port of Kuwait, US troop masses and booby trapping key bridges, etc).

3.3.1 Data and Subject Matter Experts

As previously stated, the methods and best practices of building the networks required for this method will vary wildly based on the target entity and, in practice, include classified methods and means that are therefore rightly beyond the scope of this paper. As a tool for an analyst to employ this method, there are certain patterns within existing literature which may illustrate specific PMESII layers. Once systems are identified and targeted within these layers and are modeled in higher resolution for operational exploitation, the network nature of some of these systems may in fact lend themselves to other network constructions like bipartite or min/max flow type graphs. Furthermore, the social network specifically might combinatorially expand if the operational and tactical objectives are not properly scoped through the use of a strategic method like the one purposed here.

3.4 Phase of War Considerations

JP 3-60 and JP 3-0 are military joint publications, and succinctly characterize the various Phases of War and their respective mission types [5]. Due to its military source, the figure below has activities starting in Phase One; however, this method is a Whole of Government approach and therefore must consider the adversary networks through all phases of war because the military is not the only national source of power available.

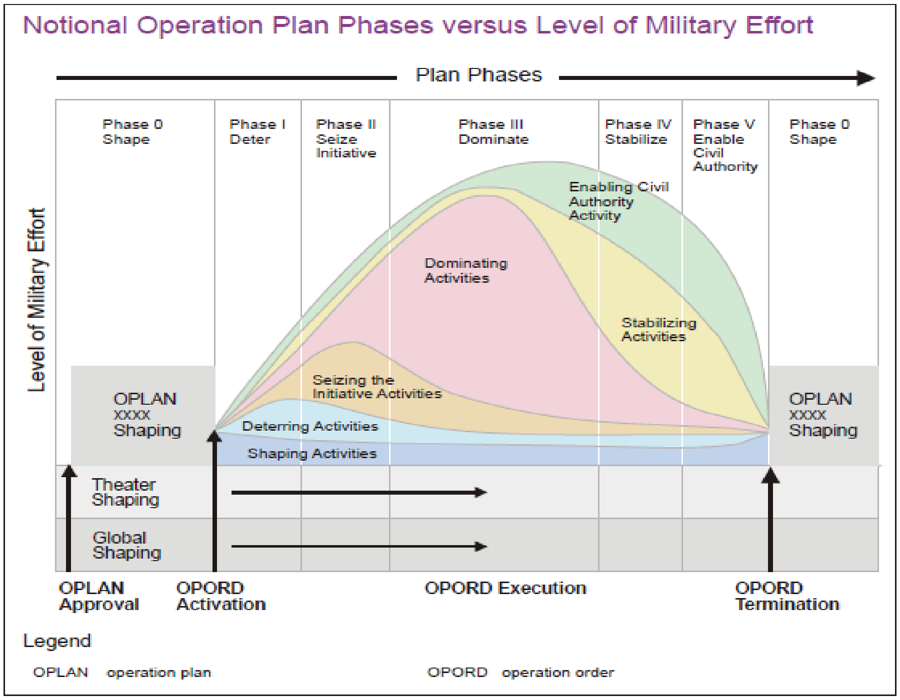

Figure 8: Doctrinal Phase of War Activity Levels [43]

For the purposes of this research, the meaning behind phrases like "OPLAN Approval" and "OPORD Activation" found in Figure 8 will not be discussed at length due to their military specific meaning and application. Phase Zero (Shaping Operations) is characterized by diplomatic and cooperative efforts seeking to influence both adversary and ally behavior alike. For the purposes of this thesis, Phase Zero objectives focus on illuminating dark networks via diplomatic and economic exposure and intelligence gathering. Phase One (Deter) is characterized by dissuading an adversary from a course of action and setting conditions if the international relationship should degrade further. In military terms, this usually means conducting special exercises and limited mobilization as a confirmation of the will to act. Phase Two (Seize Initiative) is a more forceful phase aimed at immediately halting some offending or aggressive behavior. Typical activities in this phase will transition from passive intelligence gathering and strategic influence to active intelligence gathering and operational timeframe influence and effects based missions. Phase Three (Dominate) flows naturally from Phase Two if the adversary does not immediately capitulate. It is during this phase that we utilize the target list from our method operationally instead of strategically and monitor how the adversary networks react and recover. If an attack on the Will and Dependency Networks could be conducted in such a fashion that a swift victory is achieved and subsequent network function could be restored to their previous performance, then not only can a transition from Phase Three occur quickly, but the time spent in Phase Four (Stabilize Operations) is minimized. Speaking in terms of graph theory, Phase Three is when active efforts are used to remove edges and nodes and Phase Four is where we attempt to insert friendly substitute edges and nodes to take their place with the goal of moving the target entity toward stability. Phase Five (Enable Civil Authority) represents a removal of friendly nodes and edges and supplanting them with native nodes to return the adversary to indigenous control.

3.4.1 Phase of War Value Measures

At the onset of this method, we must elicit the relative importance of the PMESII spheres from our decision maker with respect to a particular target using any method described in Section 2.6. Let us consider the notional country of 'Atlantia' whose elicited PMESII vs. Phase of War chart resembles Table 3 below:

Table 3: Altantia Attribute Weight by Phase of War

		Phase of War					
		0	**1**	**2**	**3**	**4**	**5**
Attribute	**P**	0.3	0.4	0.35	0.2	0.35	0.35
	M	0.05	0.1	0.2	0.35	0.2	0.05
	E	0.2	0.25	0.12	0.1	0.2	0.35
	S	0.2	0.1	0.05	0.1	0.2	0.05
	Info	0.2	0.1	0.1	0.1	0.01	0.05
	Infra	0.05	0.05	0.18	0.15	0.04	0.15

For this notional decision maker, Table 3 indicates that our strategic weights favor the political attribute layer for all but the military focused Phase Three. Another characteristic of this chart is that all weights obey Equation 9 over a particular Phase of War and sum to one. This property may be relaxed at the decision maker's discretion, however, each column for each Phase of War must sum to the same number to maintain relational comparability. For example, if Phase of War weights summed to 50 or 0.5, so long as the relative importance from one layer to another is maintained, this method will produce the same ordinal ranking of targets in the master target list. This is the main reason why the values calculated in the set $\{S_{i,\,Total}\}$ do not have the same utility interpretation as a Value Focused Thinking or other utility theory compliant models might.

While it would certainly be convenient to have this for planning an entire campaign through all six phases of war, in reality, these values would need to be confirmed periodically. This is especially true if the decision maker changes during the campaign, as the adversary network brightens as a result of our activities or strategic values/goals change, or a particular network is more resilient to alteration/influence than anticipated. The analyst should be ultimately concerned with the weights of all six measures and exercise caution: a careful and accurate consideration of these values will determine strategic ‘targetability’ of all the nodes within the attribute matrices. If done haphazardly, resulting actions could extremely over-attrite one network at the expense of others resulting in unnecessary damage, wasted monetary investment or even failure of the original overarching strategic intent. Therefore, sensitivity analysis of the weights should be done to determine how robust the target list is to the elicited values.

3.5 Objective Sensitive Centrality

In order to capture the relative importance within these networks of systems, this method employs centrality measure calculations. Indeed, therein lays the strength of this process: different strategic objectives can be captured using appropriate centrality measures. This research utilizes four measures to illustrate the process, but in reality there are dozens of centrality measures that an analyst could employ to capture nuance within a decision maker’s intent. Performing such objective sensitive centrality measures to the Dependency Networks (Military, Informational and Infrastructure layers) produces the “Centers of Dependency.” Likewise, performing objective sensitive centrality measures on the Will Networks yields the ranked list of the adversary’s “Centers of Will.”

The question then becomes how an analyst can interpret objectives into a centrality measure. In order to do this, one must elicit enough detail about the strategic objective to marry the decision maker’s intent to the mathematics of the centrality measure. For instance, if a decision maker states, “I want to know what is going on inside ‘Atlantia’,” the analyst must focus on the type of information and insight the decision maker desires. He/she may want insight into Atlantia’s political decision making, mood/opinions of the indigenous population, or current flow of certain economic staples. In a data collection scenario, focusing on the most highly connected systems in a particular PMESII network might be valid. Given an early stage of war and unknown size network, collecting information on a highly connected system is the logical starting position. In Section 3.6, a notional country example illustrates the entire methodology.

3.6 Sample Network Example

For illustration, we construct six random networks to represent our six attribute graphs using any method available. Here, the Prescribed Node Degree, Connected Graph (PNDCG) [46] algorithm is used to produce graphs of various node size and various settings. The settings of the PNDCG that build our networks for this example are located in Appendix A. A summarized chart of the networks built for this example is located below in Table 4. To present a degree of realism, different sized graphs are used with different probability values for connectedness.

Table 4: Example Network Snapshot

Example Network Snapshot				
Layer	Directed	Binary/Weighted	Number Nodes	Number Arcs
P	Y	W	50	641
M	N	B	60	64
E	N	B	80	86
S	Y	W	60	883
Infra	N	B	80	117
Info	N	B	100	137

As an example for this simple scenario, the Military layer for the sample set of graphs is below in Figure 9. Note that MATLAB produces a set of cycle arrows to represent an undirected graph.

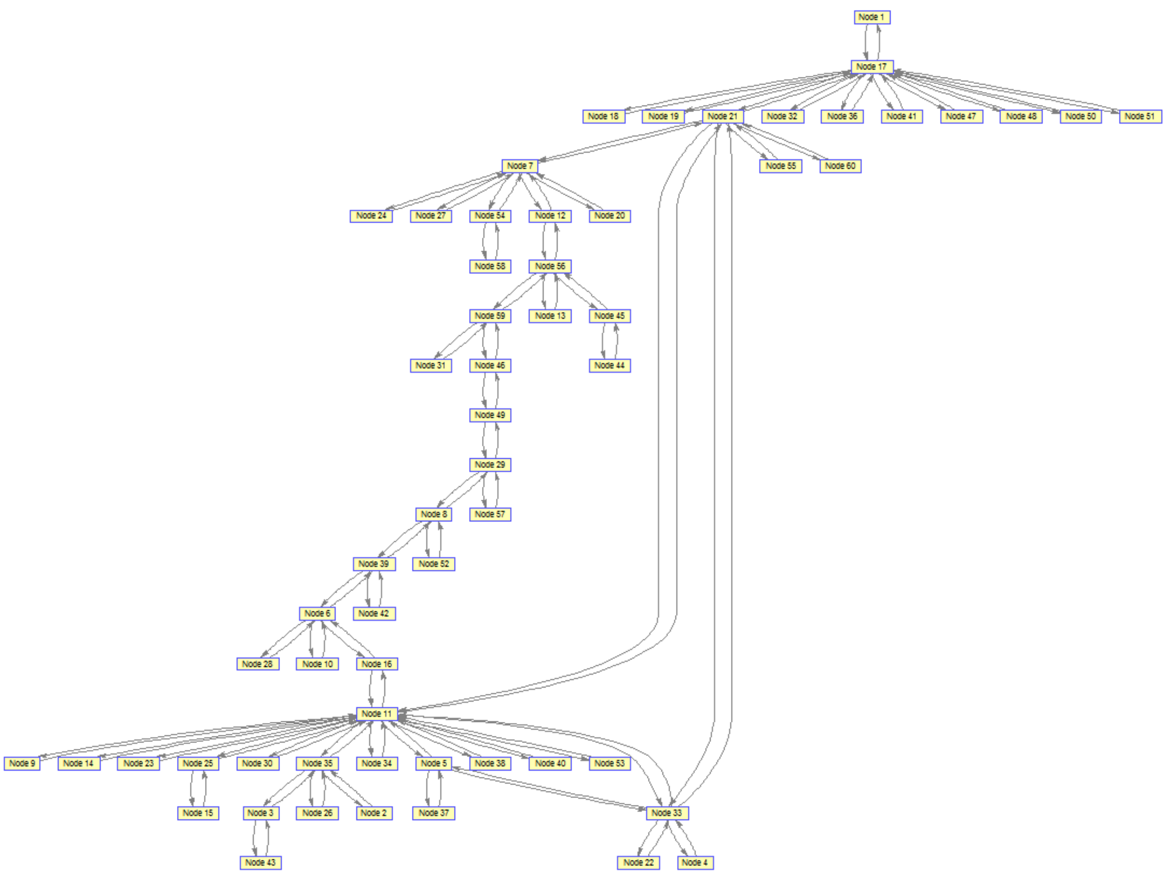

Figure 9: Sample Military Network

Utilizing the ‘Attribute Weight versus Phase of War’ chart located in Table 3 in Section 3.4.1, consider a scenario within in Phase One (Deter) concerning the notional country of ‘Atlantia’ against whom the following objectives are established:

1. Ease restrictive trade practices (political sphere)
2. Examine import flow of goods and services (economic sphere)
3. Increase positive perception of our country within their population (social sphere)
4. Identify main infrastructure hubs (infrastructure sphere)
5. Identify military installations that serve as key pre-deployment training and equipment depots (military sphere)
6. Determine the most influential information systems in Atlantia (information sphere)

3.6.1 Centrality Decisions

Examining the objectives will determine the most appropriate centrality measure to produce a strategic target list against these objectives. For objective one, the decision maker is interested in a political effect. Therefore, a defendable choice exists between degree or eigenvector centrality within the political attribute graph in order to identify key offices or political systems with which favor may be curried to achieve that effect. The choice between these two measures depends on the accessibility of the highly connected offices, systems within the political graph, or if using the most influential systems linked to the most highly connected nodes (eigenvector centrality) would be more appropriate. For this research, eigenvector centrality is used to simulate a preference to systems or offices with less overt prestige in order to minimize public exposure to friendly efforts.

Objective two is tied to intelligence gathering and asks for a flow of goods and services. Under these circumstances, the betweenness centrality is most appropriate and will produce an ordered list of economic systems that handle the most economic throughput. Objective three seeks to discover the most influential of the social systems for either positive messaging operations or monitoring of negative opinion trends of Atlantia. While eigenvector centrality is usually a good candidate for influential nodes, closeness centrality will be utilized. Closeness is favored in this case because with a systems view of the social will network, we are interested in sampling the most active social systems which can reach the greatest number of other systems through the fewest connections. This is predicated mainly on electronic shortest path connections; therefore the systems on the shortest paths between other systems in a social setting are defendable.

Objective four is a straight forward degree centrality candidate. This list will produce the hubs of all major infrastructures: water, gas, civilian transportation, airports, and so forth. Identification of these hubs will serve developmental, military, humanitarian or other operational objectives. Objective five implies another betweenness centrality measure. Military units usually flow through the same collective training locations and aerial/sea points of debarkation for deployment and as such would be identified using between centrality. Betweenness also aids in identifying key movement nodes in the case of a national deployment; this could aid military planners in structuring intelligence assets for clarity on Atlantia's military procedures. Lastly, objective six seeks to identify influential information systems. This is another candidate for eigenvector analysis due to the influential nature of the requested targets. Degree centrality would identify the information systems that are most connected; because the target is influential information systems, this implies interest in the nodes that might provide the content to those highly connected systems. Eigenvector centrality will favor and identify these systems.

3.6.2 Performing Centrality

For the next step of the method, it is required to calculate the various centrality measures against the attribute networks. For this example, the output from the PNDCG is a series of edge lists which are imported into Microsoft Excel. The nodes are re-ordered to begin at node one (the PNDCG starts at node 0). Centrality measures are then calculated in MATLAB on these modified edge lists. The centrality measures are normalized using the 2-norm as stated at the conclusion of Section 3.2 and each ordered centrality list is then multiplied by its Phase of War weight. Once these calculations are complete, it is a simple matter to array all six lists into one list and sort it in descending normalized centrality order. Below is the top forty non-Phase of War weighted systems juxtaposed with the Phase One weighting scheme proposed in Table 3, as a result of this method:

Table 5: Unweighted Final Target List

Target #	Master (unweighted)	Node	Measure
1	0.94358	IF46	degree
2	0.81723	E29	between
3	0.56049	M11	between
4	0.52892	M21	between
5	0.51066	IO17	Eigen
6	0.41235	E76	between
7	0.34776	IO28	Eigen
8	0.32024	M7	between
9	0.30842	IO67	Eigen
10	0.28626	M17	between
11	0.27119	IO46	Eigen
12	0.26666	P37	Eigen
13	0.26226	E3	between
14	0.26175	P25	Eigen
15	0.25111	P45	Eigen
16	0.23840	P10	Eigen
17	0.22842	P7	Eigen
18	0.22426	P5	Eigen
19	0.22273	P34	Eigen
20	0.21388	P23	Eigen
21	0.21055	M16	between
22	0.20328	IO99	Eigen
23	0.20316	P22	Eigen
24	0.20253	M6	between
25	0.19599	IO36	Eigen
26	0.19304	IO93	Eigen
27	0.18795	P1	Eigen
28	0.18612	P40	Eigen
29	0.18112	M12	between
30	0.18017	P9	Eigen
31	0.18005	M56	between
32	0.17180	E39	between
33	0.17115	P21	Eigen
34	0.16953	P17	Eigen
35	0.16791	S55	close
36	0.16560	S46	close
37	0.16484	S4	close
38	0.16331	IF6	degree
39	0.16149	S22	close
40	0.16052	S57	close

Table 6: Phase One Weighted Target List

Target #	Node	Measure	Master (Weighted)
1	E29	between	0.20431
2	P37	Eigen	0.10667
3	P25	Eigen	0.10470
4	E76	between	0.10309
5	P45	Eigen	0.10044
6	P10	Eigen	0.09536
7	P7	Eigen	0.09137
8	P5	Eigen	0.08970
9	P34	Eigen	0.08909
10	P23	Eigen	0.08555
11	P22	Eigen	0.08126
12	P1	Eigen	0.07518
13	P40	Eigen	0.07445
14	P9	Eigen	0.07207
15	P21	Eigen	0.06846
16	P17	Eigen	0.06781
17	E3	between	0.06556
18	P27	Eigen	0.06385
19	P41	Eigen	0.06091
20	P38	Eigen	0.05998
21	P18	Eigen	0.05805
22	P3	Eigen	0.05715
23	M11	between	0.05605
24	P50	Eigen	0.05485
25	P11	Eigen	0.05470
26	P8	Eigen	0.05383
27	M21	between	0.05289
28	IO17	Eigen	0.05107
29	P16	Eigen	0.05050
30	P6	Eigen	0.04806
31	IF46	degree	0.04718
32	P29	Eigen	0.04610
33	E39	between	0.04295
34	P2	Eigen	0.04191
35	P24	Eigen	0.04111
36	P20	Eigen	0.04063
37	P47	Eigen	0.04003
38	P15	Eigen	0.03827
39	P4	Eigen	0.03623
40	P33	Eigen	0.03584

As can be seen, the non-Phase of War weighted list in Table 5, shows that overall, no one layer or centrality measure dominates the method due to the normalization. The Phase of War weighted list in Table 6 favors the political attribute as designed, but other attributes are still present in the top forty. It is significant to mention that over 98% (425 of 430) of all systems within these sample graphs had weighted centrality scores below 0.1. This reiterates the great care that must be taken in eliciting the Phase of War weights, as weights out to three significant figures could prove substantial in the ordering of the final strategic target list.

3.7 The Final Weighted Target List

After performing this method and producing a weighted list, it becomes necessary to examine two questions: What insight does this list provide and what can be done once it has been obtained? Effectively, what this method has done is create a network proxy of a real system; it mathematically captures an overarching objective against every layer of that system; and lastly it weighs each layer's objective dependant target list on the current state of affairs between the analyzing entity and the analyzed entity. This gained insight provides repeatable, traceable and defendable relative importance for every system in the representative proxy of PMESII layers. This addresses the constant concern of employing limited resources against a complex adversary and achieves the greatest strategic effect. With such a final weighted target list, any leader could delegate actions effectively and efficiently across every capability or agency at their disposal. However, it is vital to note that targeting and effects are an iterative process. The key to this process is the assessment and adjustment loop in Figure 7. Once the targeting process is complete and friendly capabilities are acting on some element of the identified systems, the networks will react. Thus, a new snapshot of these layers must be accomplished to aid not only a new iteration of targeting, but also an assessment of the effects achieved over the last iteration of actions. Only then can an analyst provide a DM with the insight required to declare strategic success or failure, assess any changes in the Phase of War, or reassess the weights within the current Phase of War.

IV. Analysis and Results

"Tactics teaches the use of armed forces in the engagement;

strategy, the use of engagements for the object of the war."

- Carl Philipp Gottfried von Clausewitz

4.1 Introduction

This chapter examines the results obtained from the method in Chapter Three. Searches in literature provide no examples of applications of this type to describe sets of PMESII strategic networks as a whole; therefore, existing case studies do not exist against which this method might be objectively evaluated. With this in mind, the way forward includes examining robustness to network size and sensitivity to weights. First, the method will be tested through the inclusion of a single large network to ensure that results are node and edge density independent. Then this method will be applied to a realistic set of exemplar graphs created from real data. Finally, sensitivity to Phase of War valuations as well as transitions from one phase to another is examined.

4.2 Single Large Network Robustness

In order to be general and useful, the methodology in Chapter Three must be robust and offer meaningful insights and results for all conceivable size and density of networks. To test this robustness, the randomly generated networks in Chapter Three will be systematically replaced with networks based on real world phenomena. For this section, the social layer network from the example in Chapter Three is replaced by a real world example utilizing a 'Facebook-like' network first used by Dr. Opsahl in 2009 [47]. Using the weighted static one-mode network (weighted by number of messages), while keeping the rest of the networks from Chapter Three constant, an examination of the impact of the much larger network on this method can be accomplished. This 'Facebook-like' network contained 1899 nodes with well over 20,000 edges, as well as four distinct connected graphs or 'components.' When closeness centrality is applied to this network in the same fashion as the previous randomly generated social layer from Chapter Three, the largest or 'giant' component must first be isolated. If this step is eliminated, then most closeness centrality algorithms (as a function of assuming a connected network for all centrality calculations) return a zero value due to the infinite 'farness' calculation of the distance between two nodes that are not connected within the graph. Eliminating isolates for this research was done in MATLAB; however there are many techniques and software which may automate the process [48]. In so doing, this method reiterates a well known limitation in the application SNA generally, namely almost all centrality measures assume a connected graph and reality is not constrained to be necessarily connected. At the strategic level, small numbers of isolated systems might be ignored so long as those systems are truly isolated and their influence on the rest of the strategic system layer is null. In the case of the 'Facebook like' data, the isolates were three pairs of individuals sending messages only within their respective pairs.

Once the largest component is isolated, it is a relatively straight forward process to calculate closeness. As with the PNDCG random graphs from Chapter Three, the closeness calculation here is performed using MATLAB. The results are then exported to Microsoft Excel and re-ordered largest to smallest to produce a similar product to the output lists from Chapter Three. The top forty nodes in this new social layer network are displayed in Table 7 below:

Table 7: Normalized Large Social Layer Centrality

Target #	node	Normalized Closeness
1	1784	0.0790
2	1871	0.0713
3	1888	0.0614
4	1859	0.0543
5	1802	0.0526
6	1804	0.0520
7	1754	0.0489
8	1612	0.0487
9	31	0.0471
10	1203	0.0470
11	845	0.0467
12	1300	0.0458
13	791	0.0457
14	1258	0.0449
15	1869	0.0448
16	1763	0.0439
17	1027	0.0437
18	1570	0.0434
19	255	0.0433
20	1010	0.0432
21	1765	0.0430
22	1611	0.0429
23	1740	0.0426
24	1584	0.0423
25	275	0.0418
26	1442	0.0414
27	1801	0.0409
28	1082	0.0408
29	935	0.0408
30	426	0.0406
31	608	0.0402
32	1370	0.0400
33	1881	0.0400
34	1490	0.0399
35	1225	0.0399
36	1726	0.0394
37	258	0.0392
38	1663	0.0389
39	1572	0.0381
40	1892	0.0378

When compared to Table 5 from Chapter Three, it is obvious that normalized closeness values in Table 7 are approximately an order of magnitude lower than the original unweighted target list. This unfavorable order of magnitude comparison is not unique to closeness centrality. Examining Table 8, it appears both normalized eigenvector and closeness centralities either degrade too quickly or produce relatively lower numbers to compete directly with normalized degree and betweenness centrality. When the network in question is very large, then closeness centrality is initially dominated by the normalized values of the other measures for at the highest positions of the target list.

Table 8: All Normalized Measures for the Large Social Layer

Top Forty Targets by Measure								
Target #	Node	Normalized Closeness	Node	Normalized Eigenvector	Node	Normalized Between	Node	Normalized Degree
1	1784	0.0790	1624	0.1706	105	0.4237	103	0.2055
2	1871	0.0713	105	0.0806	3	0.3290	9	0.1942
3	1888	0.0614	323	0.0756	400	0.3103	105	0.1830
4	1859	0.0543	398	0.0718	9	0.2735	400	0.1830
5	1802	0.0526	12	0.0456	1283	0.2032	32	0.1668
6	1804	0.0520	1168	0.0411	103	0.1878	41	0.1475
7	1754	0.0489	9	0.0255	523	0.1712	3	0.1435
8	1612	0.0487	569	0.0188	357	0.1672	42	0.1427
9	31	0.0471	1312	0.0181	41	0.1626	249	0.1386
10	1203	0.0470	281	0.0156	67	0.1497	638	0.1362
11	845	0.0467	605	0.0142	42	0.1489	713	0.1298
12	1300	0.0458	341	0.0137	32	0.1399	194	0.1290
13	791	0.0457	431	0.0134	194	0.1275	67	0.1257
14	1258	0.0449	557	0.0132	1543	0.1218	1283	0.1225
15	1869	0.0448	32	0.0122	249	0.1186	372	0.1177
16	1763	0.0439	617	0.0116	638	0.1157	357	0.1153
17	1027	0.0437	367	0.0107	266	0.1140	12	0.1144
18	1570	0.0434	103	0.0098	176	0.1097	598	0.0991
19	255	0.0433	679	0.0091	19	0.1008	176	0.0975
20	1010	0.0432	561	0.0084	1598	0.1002	321	0.0943
21	1765	0.0430	68	0.0084	321	0.0974	1281	0.0943
22	1611	0.0429	474	0.0076	144	0.0935	704	0.0911
23	1740	0.0426	48	0.0070	704	0.0925	19	0.0887
24	1584	0.0423	95	0.0069	713	0.0896	1713	0.0887
25	275	0.0418	372	0.0065	1281	0.0878	308	0.0854
26	1442	0.0414	1118	0.0064	598	0.0781	277	0.0846
27	1801	0.0409	810	0.0061	770	0.0767	323	0.0838
28	1082	0.0408	1313	0.0059	482	0.0743	523	0.0814
29	935	0.0408	298	0.0059	44	0.0739	1543	0.0798
30	426	0.0406	704	0.0053	36	0.0671	1189	0.0798
31	608	0.0402	308	0.0053	12	0.0653	1598	0.0750
32	1370	0.0400	42	0.0052	1269	0.0639	840	0.0750
33	1881	0.0400	1756	0.0043	840	0.0591	144	0.0733
34	1490	0.0399	1644	0.0040	697	0.0591	770	0.0733
35	1225	0.0399	72	0.0040	871	0.0590	95	0.0725
36	1726	0.0394	711	0.0037	95	0.0562	36	0.0717
37	258	0.0392	1402	0.0036	323	0.0552	1624	0.0717
38	1663	0.0389	1713	0.0036	69	0.0528	325	0.0717
39	1572	0.0381	254	0.0036	53	0.0515	475	0.0709
40	1892	0.0378	249	0.0036	1189	0.0505	697	0.0693

This does not necessarily mean that closeness centrality is a ‘bad’ or incorrect measure with which to approximate a commander’s objective. However, it does imply that the analyst should ensure that closeness truly captures the objective when the network is large and densely connected. An examination of the last target number rows in Table 8 shows that closeness does produce values that are on the order of magnitude and directly comparable. While closeness centrality may not produce targets within a Center of Will or Center of Gravity, closeness still represents a viable mathematical interpretation of a DM's objective and will still produce targets represented in the top 1% of system nodes. In the example in Section 3.6.1, closeness centrality was purposely used to display this limitation; with the new social layer being much larger as compared to the other layers, betweenness or degree centrality might be better suited to answer the decision maker's objective of "increasing positive perception." In a large network, the 'increasing positive perception' objective could be interpreted as so-called gate keeper or 'go between' influence. Also of note is the fact that eigenvector, betweenness, and degree centrality, for this network, share nine of the top forty nodes or 22.5% (highlighted in Table 8). Betweenness and degree centrality for this network share thirty-three of the top forty nodes or 82.5% and maintain a directly comparable scale. Therefore, once a particular network becomes very large, targeting based on closeness may lose its interpretation and as such must be re-examined.

4.3 The Full Exemplar Substitution

Now that repercussions of performing certain centrality measures over an overwhelmingly large single system have been demonstrated and examined, all graphs from the generated example in Chapter Three are replaced by exemplar networks created from sets of real world networks to function as proxies for a set of PMESII networks. As previously stated, there is no available pool of data which describes all PMESII layers regarding a single sufficiently large entity. Therefore, the next step in validation will examine attribute-like networks and their behavior under this method.

4.3.1 Choosing the Networks

The choice of exemplar networks in this section is designed to not only use real life networks that could reasonably approximate its applicable PMESII layer, but also test the validity of this method against disparate sized networks. For the PMESII layers in this section, the PNDCG algorithm is used to create undirected exemplar graphs using six real-world data sets. The settings for all PNDCG exemplar graphs within this section can be found in Appendix B. Note that the distribution file is the same in all the settings because the exemplar graph creating function within the PNDCG algorithm requires the file to run, but does not use the values within the file for connectedness calculations in the final graphs.

The first exemplar is created from the facebook-like network from Section 4.2, producing a weighted graph. The information layer is produced via the California Web Graph from Kleinberg's datasets [49]. Next, the graph generated from the sequencing of the *C. elegans* organism worm's neural network [50] is used to represent a dense political system of systems. Each of the political, information and social graphs were weighted after their creation using the random number generator function in Microsoft Excel prior to performing centrality measures. For the proxy economic layer, a highly connected yet binary blogging network from Adamic and Glance [51] forms the basis of the exemplar graph. This graph was chosen to replicate a highly complex and integrated economy of a developed modern nation. The military network is also representative of a highly advanced entity; the exemplar use to describe it came from the densely connected 500 busiest airports network [52]. Lastly, the infrastructure network exemplar is based on the

Western US power grid network also used by Watts and Strogatz [53]. A summary of all exemplar networks is located in Table 9 below:

Table 9: Full Exemplar Substitution Summary

Layer	# Nodes	# Arcs	Weighted?
P	306	2350	Y
M	500	5961	N
E	1490	19159	N
S	1899	20296	Y
IO	9664	17895	Y
Infr	4641	6595	N

4.3.2 Targeting the Full Exemplar Substitution

The same calculations performed in Chapter Three are now repeated against the full set of exemplar graphs which represent the new PMESII layers. The only change in the method is betweenness centrality is substituted for closeness centrality when evaluating the social layer. Degree centrality is still used for the infrastructure layer. In Table 10 below, we see the Unweighted Master Target List produced by this methodology.

As in Table 5 and Table 6, Table 10 is shaded to indicate the different layers represented in the top forty targets. As seen in Table 10, it is obvious that scale has no impact on dominance as it pertains to node count or edge density. However, similar to the social layer under closeness centrality in Section 4.2, the infrastructure layer is missing from the top forty targets due to the choice of the degree centrality measure. The first occurrence of an infrastructure target is target number 125; this is still within the top 1% of nodes for our total system of 18,500 system nodes. Of note, if the social layer objective was calculated with closeness centrality, the first appearance of a social target system would have been target number 136; this is also still within the top 1% of nodes for our total system.

Table 10: Unweighted Exemplar Target List

Target #	Master (Unweighted)	Node	Measure
1	0.62748	E855	Between
2	0.46483	M1	Between
3	0.37823	M3	Between
4	0.36291	E155	Between
5	0.34888	M2	Between
6	0.32327	S194	Between
7	0.30451	E1051	Between
8	0.30144	M7	Between
9	0.29853	M6	Between
10	0.29208	S437	Between
11	0.27344	S9	Between
12	0.25978	E963	Between
13	0.25621	M21	Between
14	0.25575	S317	Between
15	0.25221	P71	Eigen
16	0.23987	E55	Between
17	0.22262	M11	Between
18	0.22133	IO1806	Eigen
19	0.21661	P72	Eigen
20	0.21647	IO9664	Eigen
21	0.21316	IO1079	Eigen
22	0.21072	M8	Between
23	0.20327	P305	Eigen
24	0.20286	S372	Between
25	0.20206	S840	Between
26	0.18706	S475	Between
27	0.18589	M18	Between
28	0.18588	P78	Eigen
29	0.18088	S277	Between
30	0.17802	M10	Between
31	0.17597	S498	Between
32	0.17576	IO235	Eigen
33	0.17445	S482	Between
34	0.17392	P73	Eigen
35	0.17280	E641	Between
36	0.17150	P76	Eigen
37	0.16817	IO2078	Eigen
38	0.16808	P74	Eigen
39	0.16512	IO6427	Eigen
40	0.16130	S103	Between

Therefore, with the results reflected in Table 10, given the disparity between node density and connectedness of our six realistic PMESII layers, it can be concluded that this method is robust to the not only node density and edge density, but also to the choice of centrality measure as well. That is not to say the final target list is robust to these factors.

Each of these factors will influence the various target nodes that appear in the final ordered strategic target list. This robustness conclusion simply means that these three factors will not result in dominance of one layer over another based solely on its characteristics or targeting objective.

4.4 Robustness by Weights and Phase of War

The purpose of this section is to demonstrate the sensitivity of this method to the Phase of War weights elicited from a decision maker. Additionally, this section demonstrates the difference between target lists from two different Phases of War. As implied from Section 3.4.1, the exact ordering of the final target list produced by this method is marginally sensitive to the weights elicited for each Phase of War. Table 10 from the previous section illustrate that this method is very robust to both node density and edge density of any respective PMESII layers we might utilize.

4.4.1 Weight Sensitivity

Examining the results of this method so far, the final value for each system across all layers appears unique to four or five significant digits. To answer how sensitive this method is the significant figures of the Phase of War weights, consider Table 12 and Table 13 below. Table 12 is calculated by applying the original weights for Phase Three. Table 13 was produced using alternate Phase Three weights. Table 11 depicts the weights used to produce the results in Table 12 and Table 13 respectively.

Table 11: Original and Alternate Phase Three Weights

Layer	PH 3	PH 3 ALT
P	0.2	0.24
M	0.35	0.345
E	0.1	0.12
S	0.1	0.07
IO	0.1	0.08
Infr	0.15	0.145

From Table 12 and Table 13 below, the full target list changes order slightly when alternate Phase Three weights are applied. The military, economy, and political layers' nodes within the top forty changed an average of 2.13, 2.75, 2.31 positions respectively. The social layer's nodes changed an average of 32 positions. Though this change removes social layer targets from the top forty, this is not significant given that all six layers taken together sum to a total of 18,500 nodes. In terms of providing insight, this movement in position may alter a DM's perspective on the relative importance between the layers. However, in terms of assigning targets to capability within an organization, this is insignificant within 1% of the targeted nodes.

Table 12: Phase Three Target List

Target #	Node	Measure	Master (Weighted)
1	M1	Between	0.16269
2	M3	Between	0.13238
3	M2	Between	0.12211
4	M7	Between	0.10550
5	M6	Between	0.10449
6	M21	Between	0.08967
7	M11	Between	0.07792
8	M8	Between	0.07375
9	M18	Between	0.06506
10	E855	Between	0.06275
11	M10	Between	0.06231
12	P71	Eigen	0.05044
13	M5	Between	0.04968
14	M12	Between	0.04900
15	P72	Eigen	0.04332
16	M15	Between	0.04136
17	P305	Eigen	0.04065
18	P78	Eigen	0.03718
19	E155	Between	0.03629
20	P73	Eigen	0.03478
21	P76	Eigen	0.03430
22	M17	Between	0.03419
23	P74	Eigen	0.03362
24	S194	Between	0.03233
25	P75	Eigen	0.03166
26	M4	Between	0.03149
27	P217	Eigen	0.03085
28	P77	Eigen	0.03074
29	P216	Eigen	0.03071
30	P178	Eigen	0.03065
31	E1051	Between	0.03045
32	S437	Between	0.02921
33	P117	Eigen	0.02808
34	P81	Eigen	0.02778
35	M37	Between	0.02762
36	S9	Between	0.02734
37	P82	Eigen	0.02706
38	E963	Between	0.02598
39	P118	Eigen	0.02577
40	S317	Between	0.02558

Table 13: Phase Three Alternate Target List

Target #	Node	Measure	Master (Weighted)
1	M1	Between	0.16037
2	M3	Between	0.13049
3	M2	Between	0.12036
4	M7	Between	0.10400
5	M6	Between	0.10299
6	M21	Between	0.08839
7	M11	Between	0.07681
8	E855	Between	0.07530
9	M8	Between	0.07270
10	M18	Between	0.06413
11	M10	Between	0.06142
12	P71	Eigen	0.06053
13	P72	Eigen	0.05199
14	M5	Between	0.04897
15	P305	Eigen	0.04879
16	M12	Between	0.04830
17	P78	Eigen	0.04461
18	E155	Between	0.04355
19	P73	Eigen	0.04174
20	P76	Eigen	0.04116
21	M15	Between	0.04077
22	P74	Eigen	0.04034
23	P75	Eigen	0.03799
24	P217	Eigen	0.03703
25	P77	Eigen	0.03689
26	P216	Eigen	0.03686
27	P178	Eigen	0.03678
28	E1051	Between	0.03654
29	M17	Between	0.03370
30	P117	Eigen	0.03370
31	P81	Eigen	0.03333
32	P82	Eigen	0.03247
33	E963	Between	0.03117
34	M4	Between	0.03104
35	P118	Eigen	0.03093
36	P90	Eigen	0.03027
37	P219	Eigen	0.02997
38	P51	Eigen	0.02979
39	P198	Eigen	0.02925
40	E55	Between	0.02878

4.4.2 Phase of War Sensitivity

It is well known in military planning circles that friction exists during periods of transition, but this truism is not unique to the military. This observation is true for almost any transition at any level: political leadership changes, corporate restructuring/evolution, personal major life events and shocks to group dynamics. From a military perspective, this lesson was violently apparent during the transition from major combat operations to civil stability operations during OIF. In terms of this model, operations conducted after the declaration of the end of major combat operations made by then President George W. Bush on 1 May 2003 on board the USS Abraham Lincoln, should have been conducted under the strategic target list produced by Phase Four objectives and weights.

Unfortunately, the adversary maintained a level of military action that interfered with the US led coalition's ability to target according to Phase Four objectives and held the country of Iraq awkwardly between Phases Three and Four. One could argue that the Iraqi insurgency following the end to major combat operations resulted from an over attrition of the military PMESII network (not only through direct force on force attrition, but also from dismantling the Iraqi armed forces during reconstruction) as well as improper targeting of the social and informational layers.

This apparent disparity between the phases and the stark differences in how each phase is weighted is illustrated when Table 14 below is directly compared to Table 12 above. Note that the objectives concerning the PMESII layers have not changed; this represents a declaration of transition without an alteration in strategic objectives to accompany it. Table 14 was calculated using the same centrality measures as Table 12 and weighted according to the Phase Four weights from Table 3.

Table 14: Phase Four Weighted Target List

Target #	Node	Measure	Master (Weighted)
1	E855	Between	0.12550
2	M1	Between	0.09297
3	P71	Eigen	0.08827
4	P72	Eigen	0.07581
5	M3	Between	0.07565
6	E155	Between	0.07258
7	P305	Eigen	0.07115
8	M2	Between	0.06978
9	P78	Eigen	0.06506
10	S194	Between	0.06465
11	E1051	Between	0.06090
12	P73	Eigen	0.06087
13	M7	Between	0.06029
14	P76	Eigen	0.06002
15	M6	Between	0.05971
16	P74	Eigen	0.05883
17	S437	Between	0.05842
18	P75	Eigen	0.05541
19	S9	Between	0.05469
20	P217	Eigen	0.05400
21	P77	Eigen	0.05380
22	P216	Eigen	0.05375
23	P178	Eigen	0.05363
24	E963	Between	0.05196
25	M21	Between	0.05124
26	S317	Between	0.05115
27	P117	Eigen	0.04914
28	P81	Eigen	0.04861
29	E55	Between	0.04797
30	P82	Eigen	0.04735
31	P118	Eigen	0.04510
32	M11	Between	0.04452
33	P90	Eigen	0.04414
34	P219	Eigen	0.04370
35	P51	Eigen	0.04345
36	P198	Eigen	0.04266
37	M8	Between	0.04214
38	P96	Eigen	0.04145
39	S372	Between	0.04057
40	S840	Between	0.04041

As can be seen by comparing Table 12 and Table 14, this transition produces an entirely different set of priorities for strategic targeting even given the exact same ordinal organization of the PMESII layers produced from the centrality measures. For the purposes of this research, this shows that strategic priorities can be captured through careful elicitation of Phase of War weights. In model implementation terms, the differences between Table 12 and Table 14 are significant enough to consider a continuous function during a transition phase anchored at the departing phase value and terminating at the entering phase value.

4.5 Conclusion

While inadequate unclassified data exists to directly validate this method, this chapter has shown robustness to node density, edge density and centrality measure. Phase of War weights will produce very different target lists which reflect the strategic vision for that specific phase; however the implementation of this method may require the addition of transition phase functions which will smooth the strategic target lists from one phase to another. This research and methodology is unique due to the robustness of this model and the insights that might be gained at the strategic echelon.

V. Conclusions and Recommendations

"Many, who should know better, think that wars can be decided by soulless machines, rather than by the blood and anguish of brave men."

- George S. Patton Jr.

5.1 Study Summary

In summary, this study formulated and demonstrated a method through which a complex and chaotic strategic level problem could be captured. The techniques described in this research can be applied to international relations, military operations, and transnational business. Though expressed in terms of military and government operations, there is nothing within this research that would limit the application of this methodology to strictly governmental concerns. However, in military terms, what this research does convey is what may have once been considered a single target, can be considered many independent systems within different PMESII layers. For example a particularly large military base might have rail transportation through it, significant economic impact to its surroundings, a large infrastructural footprint, large social input as well as significant political sway due to the population (assuming representative form of government) of soldiers at the base. To a current military planner, such an installation may represent a single target; however, under this method, systems that represent the base are separate and may only by 'important' within a specific PMESII layer. Once performed, this method then tacitly indicates which DIME element should be applied to the target system.

5.2 Method Overview

This research created strategic target lists using the objective-based importance of systems within PMESII layers and weighted by the applicable Phases of War. In so doing, it has been demonstrated that not only can strategic objectives be captured in the form of centrality measures, but it is also possible to weight objective-base centrality measures, within specific PMESII layers, against one another, to obtain an overall strategic targeting list. Furthermore, to include the dynamic nature of conflict across the continuum of war, this method can be iterated across all Phases of War to reflect the DM's changing values as it pertains to strategic targeting and target lists. This research draws upon the military contributions in the SNA field from several contributors, notably Clark, Geffre, Morris, McGuire and Hamill as well as the theoretical underpinnings of traditional SNA from Borgatti, Carley, Wasserman and Faust. The method discussed within this research then builds a strategic military targeting and Clauswitzian targeting framework upon the foundation of SNA. As a result, this research provides the military analysis community with a tool for allowing a decision maker insight into complex strategic level problems.

5.3 Objectives of Research

The primary objective of this research was to expose complex system-of-systems strategic problems to SNA measures and create a weighted additive model for producing strategic targeting lists. Without delving into the means and methods of constructing such networks, this research showed that constructing network representations of adversary PMESII layers, applying objective-based centrality measures to the layers, and then weighing and combining the resultant sets produces a viable first step in strategic targeting.

5.4 Significance Contributions of Research

The method described in this research represents a natural progression of military applications of SNA theory. The contributions from this new approach are threefold. First, it demonstrates that a decision maker's objectives might be captured with a centrality measure. Once accomplished, this measure can be applied against the target network to produce a viable 1 to *n* ranking of all target nodes within the network. Second, it suggests a change in the way strategic problems are framed. By focusing on the PMESII layers and how they are constructed and weighted before assigning objectives against them ensures that the target country or entity is reviewed holistically, not through an effect-based microscope. The last contribution of this research is to show that, in a system-of-systems representation, it is possible to calculate a Clausewitz Center of Gravity. The interpretation here is that such a center of gravity is dependent on the objective or effect a decision maker wishes to impart as well as the Phase of War during which the decision is made. The Joint Publication 1-02 definition a center of gravity is "the source of power that provides moral or physical strength, freedom of action, or the will to act." [40] In this research, through calculations against the dependency and will networks, we have effectively found PMESII centers of gravity in a mathematically defensible and traceable fashion.

5.5 Recommendations for Future Research

While this method is a new approach for insights into the strategic targeting process, it can be strengthened with the addition of follow on research. Over the course of this research there were many topics that were not included. First and foremost, the current sets of centrality measures need to be examined for use in describing military objectives and mission sets. The four measures used in this research were for illustrative purposes. This implies that follow on research could also examine the creation of more sophisticated measures which more accurately capture the nuance of a DM's objectives and compare results to comparable networks used here. Further, additional research into this method could include methods to incorporate multiple objectives within each layer. This might involve weighed centrality measures or confounding the measures in some fashion to reflect a combined objective.

As to the networks themselves, this research made use of connections ranging from zero to one. Follow on research could extend the range of relational strengths to negative one to zero range to incorporate negative effects within the model and expand Clark's work into this method for strategic application. This research also considered only independent PMESII networks. Independence was accepted due to the aggregated systems-of-systems approach. Obviously, attempting to attack or influence one or more of the geographically coexisting PMESII layer nodes may have an effect on the untargeted nodes present, depending on the tactics chosen. Therefore, while the systems may be considered to be independent, the effect of targeting a particular system may not be. Future research could examine this effect-based dependence as a function of PMESII layer interdependence or, a time-dependent resiliency reaction from other networks in response to the targeted system. Unfortunately, unclassified data could not be found to differentiate these effects and account for them to increase the predictive power of this method in its current form.

Lastly, referring to Figure 3, the next step in this targeting process should involve a DIME assignment process for the tasking of these targets to capability. This could involve an optimization or Value Focused Thinking approach to determining which mix of targets is ideal to forward a particular strategy set within a particular Phase of War. This might be coupled with an analysis of multiple objectives per PMESII layer; target packages could then be scored according to how many objectives the target mix satisfies.

5.6 Conclusion

The need for a set of strategic tools and methods is apparent from the US military's use of force in the latter half of the 20th century and the 21st century to date. As the advance of technology continues to provide both positive and negative effects across developed nations, the manner in which we develop strategies to engage with our allies as well as dissuade our adversaries must evolve and maintain flexibility. When strategies are built through a holistic review of all PMESII layers, such a strategy provides a clearer vision, better coordination of effect, and a cogent intent that subordinate decision makers can readily understand.

Appendix A: PNDCG Settings for Atlantia Network

Economic Network:

IS_DIRECTED	N
RANDOM_SEED	20
NUM_NODES	80
PCT_DEVIATION_FROM_EX	100
EX_FILE	ex_U_1000.txt
DEGREE_DIST	2
POWER_DIST_EXP	2.6
DEGREE_DIST_FILE	econdist.txt
PCT_CLUSTERING	0
NUM_OUTPUT_FILES	5
OUTPUT_FILE_START_NUM	1
OUTPUT_DATA_FILE	outputgraph.txt

Economic Degree Dist File:

.3
.2
.4
.1

Information Network:

IS_DIRECTED	N
RANDOM_SEED	5
NUM_NODES	100
PCT_DEVIATION_FROM_EX	100
EX_FILE	ex_U_1000.txt
DEGREE_DIST	2
POWER_DIST_EXP	2.6
DEGREE_DIST_FILE	econdist.txt
PCT_CLUSTERING	0
NUM_OUTPUT_FILES	5
OUTPUT_FILE_START_NUM	1
OUTPUT_DATA_FILE	outputgraph.txt

Information Network Degree Dist File:

.1
.1
.5

Infrastructure Network:

```
IS_DIRECTED               N
RANDOM_SEED               0
NUM_NODES                 80
PCT_DEVIATION_FROM_EX     100
EX_FILE                   ex_U_1000.txt
DEGREE_DIST               2
POWER_DIST_EXP            2.6
DEGREE_DIST_FILE          econdist.txt
PCT_CLUSTERING            0
NUM_OUTPUT_FILES          5
OUTPUT_FILE_START_NUM     1
OUTPUT_DATA_FILE          outputgraph.txt
```

Infrastructure Network Degree Dist File:

```
.05
.05
.4
.5
```

Military Network:

```
IS_DIRECTED               N
RANDOM_SEED               30
NUM_NODES                 60
PCT_DEVIATION_FROM_EX     100
EX_FILE                   ex_U_1000.txt
DEGREE_DIST               2
POWER_DIST_EXP            2.6
DEGREE_DIST_FILE          econdist.txt
PCT_CLUSTERING            15
NUM_OUTPUT_FILES          5
OUTPUT_FILE_START_NUM     1
OUTPUT_DATA_FILE          outputgraph.txt
```

Military Network Degree Dist File:

```
.1
.3
.4
```

Political Network:

IS_DIRECTED	Y
RANDOM_SEED	50
NUM_NODES	50
PCT_DEVIATION_FROM_EX	100
EX_FILE	ex_U_1000.txt
DEGREE_DIST	1
POWER_DIST_EXP	2.2
DEGREE_DIST_FILE	poldist.txt
PCT_CLUSTERING	20
NUM_OUTPUT_FILES	5
OUTPUT_FILE_START_NUM	1
OUTPUT_DATA_FILE	outputgraph.txt

Political Network Degree Dist File:

.2
.3
.4
.1

Social Network:

IS_DIRECTED	Y
RANDOM_SEED	10
NUM_NODES	60
PCT_DEVIATION_FROM_EX	100
EX_FILE	ex_U_1000.txt
DEGREE_DIST	1
POWER_DIST_EXP	2.2
DEGREE_DIST_FILE	socdist.txt
PCT_CLUSTERING	10
NUM_OUTPUT_FILES	5
OUTPUT_FILE_START_NUM	1
OUTPUT_DATA_FILE	outputgraph.txt

Social Network Degree Dist File:

.3
.2
.4
.1

Appendix B: PNDCG Settings for Exemplar Substitutions

Social Network:

IS_DIRECTED	N
RANDOM_SEED	15
NUM_NODES	1899
PCT_DEVIATION_FROM_EX	0
EX_FILE	facebook.txt
DEGREE_DIST	3
POWER_DIST_EXP	1.8
DEGREE_DIST_FILE	dist.txt
PCT_CLUSTERING	10
NUM_OUTPUT_FILES	4
OUTPUT_FILE_START_NUM	1
OUTPUT_DATA_FILE	outputgraphA.txt

Economic Network:

IS_DIRECTED	N
RANDOM_SEED	3
NUM_NODES	1490
PCT_DEVIATION_FROM_EX	0
EX_FILE	blogosphere.txt
DEGREE_DIST	3
POWER_DIST_EXP	2.0
DEGREE_DIST_FILE	dist.txt
PCT_CLUSTERING	8
NUM_OUTPUT_FILES	4
OUTPUT_FILE_START_NUM	1
OUTPUT_DATA_FILE	outputgraphA.txt

Political Network:

IS_DIRECTED	N
RANDOM_SEED	46
NUM_NODES	306
PCT_DEVIATION_FROM_EX	0
EX_FILE	elegans.txt
DEGREE_DIST	3
POWER_DIST_EXP	1.8
DEGREE_DIST_FILE	dist.txt
PCT_CLUSTERING	5
NUM_OUTPUT_FILES	4
OUTPUT_FILE_START_NUM	1
OUTPUT_DATA_FILE	outputgraphA.txt

Infrastructure Network:

IS_DIRECTED	N
RANDOM_SEED	20
NUM_NODES	4941
PCT_DEVIATION_FROM_EX	0
EX_FILE	powergrid.txt
DEGREE_DIST	3
POWER_DIST_EXP	2.5
DEGREE_DIST_FILE	dist.txt
PCT_CLUSTERING	10
NUM_OUTPUT_FILES	4
OUTPUT_FILE_START_NUM	1
OUTPUT_DATA_FILE	outputgraphA.txt

Military Network:

IS_DIRECTED	N
RANDOM_SEED	10
NUM_NODES	500
PCT_DEVIATION_FROM_EX	0
EX_FILE	airport.txt
DEGREE_DIST	3
POWER_DIST_EXP	1.7
DEGREE_DIST_FILE	dist.txt
PCT_CLUSTERING	0
NUM_OUTPUT_FILES	3
OUTPUT_FILE_START_NUM	9
OUTPUT_DATA_FILE	outputgraphb2.txt

Information Network:

IS_DIRECTED	N
RANDOM_SEED	1
NUM_NODES	9664
PCT_DEVIATION_FROM_EX	0
EX_FILE	cali.txt
DEGREE_DIST	3
POWER_DIST_EXP	2.1
DEGREE_DIST_FILE	dist.txt
PCT_CLUSTERING	0
NUM_OUTPUT_FILES	3
OUTPUT_FILE_START_NUM	1
OUTPUT_DATA_FILE	outputgraphA.txt

AN APPLICATION OF SOCIAL NETWORK ANALYSIS ON MILITARY STRATEGY, SYSTEM NETWORKS AND THE PHASES OF WAR

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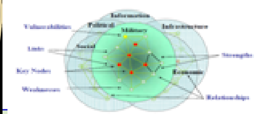


Problem Statement:

Create comprehensive Whole of Government, Phase of War dependant targeting methodology using objective-dependant centrality measures by considering large descriptive Political, Military, Economic, Social, Infrastructure and Information (PMESII) strategic level systems of systems networks within the DIME spheres of influence

Research Objectives:

- Provide a robust and agile framework to drive the Whole of Government strategic targeting process through quantitative social network and operations research techniques
- Propose a Mathematically based method to conduct Strategic Targeting
- Show that Centrality Measures can represent Decision Maker's Objective

The Strategic Targeting Model

Hard Targets, Infrastructure (Binary/Undirected)

Mil
Infra
Info

Soft Targets, Human Systems (Directed/Weighted)

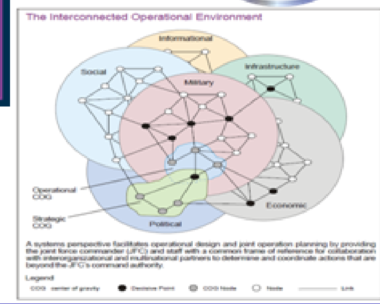
Pol
Soc
Econ

Phase of War PMESII Rank elicitation

Attribute focused Objectives elicitation; What does DM want to do to the network?

Match/Create Centrality measure to capture Objective

Generate Lists of systems of interest to achieve strategic effect



A systems perspective facilitates operational design and joint operation planning by providing the joint force commander (JFC) and staff with a common frame of reference for collaboration with interorganizational and multinational partners to determine and coordinate actions that are beyond the JFC's command authority.

Legend: COG center of gravity; Decisive Point; COG Node; Node; Link

General Method

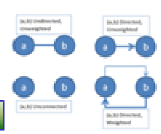
Identify large Organization → Build initial B/U network → Build initial W/O human network → Determine Applicable phase of War → Rank possible Objectives → Determine centrality measures → Intel Update; update networks → Calculate key systems based on objectives

Degree: $C_D = \sum_{j=1}^{n} A_{ij}$

Closeness: $C_C(n_i) = \left[\sum_{j=1}^{g} d(n_i, n_j)\right]^{-1}$

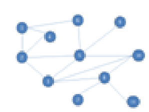
Betweenness: $C_B(n_i) = \sum_{j<k} \frac{g_{jk}(n_i)}{g_{jk}}$

Eigenvector: $(A - \lambda_i I)C = 0$



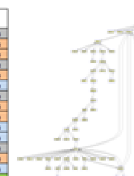
Sponsor: SOCOM JX/SCSO

Example Network Snapshot				
Layer	Directed	Binary/Weighted	Number Nodes	Number Arcs
P	Y	W	50	641
M	N	B	60	64
E	N	B	80	86
S	Y	W	60	883
Infra	N	B	80	117
Info	N	B	100	137



Full Exemplar Summary			
Layer	# Nodes	# Arcs	Weighted?
P	306	2350	Y
M	500	5961	N
E	1490	19159	N
S	1899	20296	Y
IO	9664	17895	Y
Infr	4641	6595	N

Target #	Master (Unweighted)	Node	Measure
1	0.62748	E855	Between
2	0.48483	M1	Between
3	0.37823	M3	Between
4	0.36291	E155	Between
5	0.34888	M2	Between
6	0.32327	S194	Between
7	0.30451	E1051	Between
8	0.30144	M7	Between
9	0.29853	M6	Between
10	0.29208	S437	Between
11	0.27944	S9	Between
12	0.25978	E963	Between
13	0.25621	M21	Between
14	0.25575	S317	Between
15	0.25221	P71	Eigen
16	0.23987	E55	Between
17	0.22282	M11	Between
18	0.22153	IO1806	Eigen
19	0.21661	P72	Eigen
20	0.21647	IO9664	Eigen
21	0.21516	IO1079	Eigen
22	0.21072	M8	Between
23	0.20527	P505	Eigen
24	0.20286	S372	Between
25	0.20206	S840	Between
26	0.18706	S475	Between
27	0.18589	M18	Between
28	0.18588	P78	Eigen
29	0.18088	S277	Between
30	0.17802	M10	Between
31	0.17587	S498	Between
32	0.17576	IO235	Eigen
33	0.17445	S482	Between
34	0.17382	P73	Eigen
35	0.17280	E641	Between
36	0.17150	P76	Eigen
37	0.16817	IO2078	Eigen
38	0.16808	P74	Eigen
39	0.16512	IO6427	Eigen
40	0.16130	S103	Between



Conclusions:

1. Current system of upper echelon strategic planning can be augmented and strengthened through a System-of-Systems approach to PMESII layers using Social Network Analysis
2. This Strategic Targeting Model is robust to realistic independent networks
3. This model will produce a viable target list of systems to be delegated across executive agencies or asset capabilities

Contributions:

1. Traceable, repeatable Methodology for Strategic Targeting and Insight
2. Scalable Framework allows from strategic to tactic level problems in System-of-System Networks
3. Mathematically calculated a set of Clausewitzian CoGs by Phase of War and PMESII Layer
4. Mathematically Captured Decision Maker's objective as a Centrality Measure

Appendix C: Quad Chart

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Biography

MAJ Thomas S. Furman graduated from West Springfield High School, Springfield, VA. He completed a Bachelors of Arts in Physics from the University of Virginia, Charlottesville, VA in May 2004. Upon graduation, he was commissioned into the United States Air Force through the Reserved Officer Training Corps (ROTC) Detachment 890, University of Virginia. After two years, he transferred to the Army via the Blue to Green program.

His first Army assignment was to 3d Armored Cavalry Regiment, Fort Hood, TX. There he performed as a Tank Platoon Leader, Troop Executive Officer, Squadron Battle Captain and lastly as a SIGINT driven element commander. In this last position, he used various sources of intelligence to model and target high value individuals within the Mosul and Ninewah Province Area of Operations in support of OPERATION IRAQI FREEDOM. After an intervening Army course, he was then stationed in Fort Bliss, TX, where he performed as a Division Chief Planner on two separate occasions, Battalion Executive Officer, Operations Officer and Assistant Operations Officer during the establishment of 1-6 Infantry, 2/1 AD and Commander, Headquarters Support Company, 1AD. He was selected to study Operations Research at the Air Force Institute of Technology, Graduate School of Engineering and Management. Upon graduation, he will attend Command and General Staff College, Fort Leavenworth, KS.

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14. ABSTRACT

The research developed in this study will utilize Social Network and Graph Theory terminology and methodology applied to groups of systems, rather than individuals within a given system, in order to shape strategic level goals. With regard to military operations, Social Network Analysis has been used to show that enemy networks and relationships can be accurately represented using weighted layers with weighted relationships in order to identify the key player(s) that must be influenced and/or removed so that a particular effect on the enemy might be realized. Social Network Analysis is therefore a significant tool concerning tactical level of operations that aids in developing a targeting methodology which aids tactical commanders in mission planning, however has never been applied to strategic levels of Command. Like previous key player problems, this research will utilize system attributes and global relational strengths as inputs. The output results will rank order representative systems of interest that satisfy the constraints and desired objectives within a particular Phase of War. This work will apply and extend the tools of Social Network Analysis structure and techniques to a theater level mission.

15. SUBJECT TERMS

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